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ANNALS OF THE NEW YORK ACADEMY OF SCIENCES

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A PHYSIOLOGICAL STUDY OF THE
CHANGES IN *MUSTELUS CANIS*

PRODUCED BY MODIFICATIONS IN THE
MOLECULAR CONCENTRATION OF
THE EXTERNAL MEDIUM

BY

G. G. SCOTT



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A PHYSIOLOGICAL STUDY OF THE CHANGES IN *MUSTELUS* *CANIS* PRODUCED BY MODIFICATIONS IN THE MOLECULAR CONCENTRATION OF THE EXTERNAL MEDIUM¹

By G. G. SCOTT

(Presented by title before the Academy, 10 March, 1913)

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INTRODUCTION

Differences in osmotic pressure have been held to explain many physiological processes. It is a great temptation, for example, to ascribe the passage of materials into and out of the cell to differences in molecular concentration between the cell contents and the circulating medium; and yet, such a process as the secretion of urine is not satisfactorily explained by the physical theories of osmosis and diffusion. It does not necessarily follow, however, that, because these theories in our present state of knowledge fall short of a complete explanation of physiological processes, they should on that account be altogether discarded, nor should this be taken as an argument for vitalism. The full understanding of both the physical process and the associated chemical process would make clear the physiological process. So that everything that can be ascertained with regard to the passage of materials through membranes is of value to the science of physiology.

A common method of determining the osmotic pressure of a solution is by means of a determination of its freezing point. The degree of depression of the freezing point of the solution below that of pure water is proportional to the osmotic pressure of the solution. The amount of the depression of the freezing point, or Δ , is usually obtained by the use of the Beckmann apparatus. The form of apparatus that was used in the determinations described in this paper was made by Goetz of Leipzig. When in constant use at low temperature, there is a tendency toward a slight re-arrangement of the molecules of the glass tube, and this results in a contraction that is sufficient to introduce a slight error in the readings. It is therefore advisable for any one working with this instrument to make frequent determinations of the freezing point of pure water. In the experiments here described, this procedure was followed and the proper correction was always made in the calculations.

Various aspects of the osmotic relations of the body fluids of aquatic animals to the surrounding medium have been fruitfully investigated. The waters of the earth differ in their molecular concentration. Fresh water contains but a very small amount of salts in solution. The water of the ocean, with a specific gravity of 1.025, contains about 3.0 per cent of salts in solution. The water of the Black Sea and the Baltic Sea contain less salts than the water of the ocean because of the great influx into them of river water. The Mediterranean and Red Seas on the other hand contain more salts in solution than ocean water because of the excess of evaporation over the inflow of fresh water. There is considerable varia-

tion in the osmotic pressure of the body fluids of animals that inhabit these various waters. For example, the blood of fresh water invertebrates and fishes is much more concentrated than the water in which they live. While the body fluids of these forms is maintained at a constant osmotic pressure, the surrounding water is by no means isotonic with the blood serum. The Δ of fresh water is 0.025° , while that of the blood of fresh water fishes is about 0.60° . The blood of marine invertebrates and elasmobranch fishes has about the same molecular concentration as that of the sea. The mean Δ of the waters of the Mediterranean Sea and the mean Δ of the body fluids of the invertebrates and elasmobranch fishes which inhabit it is 2.29° . The Δ of the water of the ocean is about 2.00° and invertebrates inhabiting such waters have a similar Δ . In the case of the elasmobranchs, it has been claimed that the surrounding medium is isotonic with the blood. On the other hand, the Δ of the blood of marine teleosts is less than one-half that of the external medium. For example, although the Δ of sea-water from the Baltic is 1.80° , according to Dekhuysen ('04) the Δ of the blood of marine teleosts from these waters is only 0.724° . The Δ of the blood of fresh water fishes is nearly the same as that of the marine teleosts. The blood of other marine vertebrates, such as chelonia and cetacea, and of the other fresh water and land vertebrates is similar in its osmotic pressure to that of the marine teleosts.

In view of the fact that the elasmobranchs constitute the highest group to possess blood and other body fluids with an osmotic pressure near to that of sea-water, it appeared to the present writer that an extensive investigation should be made of the effects of changes in the molecular concentration of sea-water upon the blood and other tissues of the elasmobranchs. Since a dilution, rather than a concentration, of the sea-water would be the modification of the external medium to which these fishes might be subjected in a state of nature, more attention was given to the effect of dilutions of the external medium.

In physical experiments of an osmotic nature, two solutions are separated by a membrane and the qualitative relations of the process by which the fluids pass through the membrane is studied. In the present investigation, the membrane with which we have to do is possibly one or any combination of three living structures which separate the living substance of the body from the sea-water. These three structures are: *a*, the skin of the body; *b*, the mucous membrane of the enteric canal; *c*, the membrane of the gills. In the following pages, these will be termed the limiting membranes of the body. Outside of these membranes is the sea-

water. Within the body, the rapidly circulating blood comes into such relation with sea-water as to insure the exchange of gases. It is a common belief that, by virtue of these structures alone, the organism is maintained in osmotic equilibrium with the surrounding medium. How far is this position tenable?

The relation of each of these structures to the solution within and without the organism may be that of a freely permeable membrane, a semi-permeable membrane or an impermeable membrane. The limiting membranes of the marine invertebrate body have been shown to be quite freely permeable. Sea-water is isotonic with its blood; but if the sea-water is diluted, salts leave the body by way of these structures, and water from without enters into the body with the result that the blood soon attains the same molecular concentration as the outside medium. Similar adjustments are said to take place in the case of the elasmobranchs. In this case, however, it is claimed that the resulting equality is attained not by the loss of salts from the body but by changes in the relative amount of water in the blood. Further investigation of this matter seems necessary. In addition the following questions call for investigation. What are the lethal limits of departure from the normal osmotic pressure of the blood of elasmobranchs? Is the modification in the osmotic pressure of this blood dependent upon the time of immersion in the changed external medium? Is the change dependent upon the degree of change in the osmotic pressure of the external medium? Does a lethal change in the osmotic pressure of the blood affect the corpuscles? If so, in what manner and to what degree? What is the effect of the modified blood upon blood pressure, heart beat and respiration? Is there any evidence of a mechanism for the maintenance of the normal osmotic pressure of the blood? Is there any evidence that a new and permanent normal osmotic pressure of the blood is established under conditions in which the concentration of the external medium is permanently modified? Does the blood of the elasmobranch under such conditions remain of the same molecular concentration as that of the modified external medium? Evidence on these and related problems is offered in the present paper.

The experiments described below were carried on at the Biological Laboratory of the United States Bureau of Fisheries at Woods Hole, Massachusetts, and at the New York Aquarium. I wish to thank the Commissioner of Fisheries, the Hon. George M. Bowers, Dr. Francis B. Sumner and Mr. T. E. B. Pope for the many facilities extended at Woods Hole, and to extend thanks likewise to Dr. Charles H. Townsend, the

Director of the New York Aquarium. I must also express my indebtedness to Professors Frederic S. Lee and F. H. Pike of the Department of Physiology of Columbia University for many helpful suggestions.

HISTORICAL

Sumner ('06) published a brief summary of investigations of the osmotic relations of the body fluids of aquatic animals to their surrounding medium. Bottazzi ('07) has given an extensive review of the literature bearing on this subject. I will limit this synopsis, therefore, to a brief statement of investigations on the osmotic relations of the elasmobranchs to the surrounding medium. Constant reference will be made to investigations on other forms in the pages that follow.

Mosso ('90) observed that elasmobranchs died very soon after being placed in fresh water. He explained the death as being due to the fact that the erythrocytes were laked by the influx of fresh water into the capillaries of the gill membranes, that the capillaries were clogged up with these broken down corpuscles, that circulation was thus stopped and that death ensued from asphyxiation. Von Schroeder ('90) found a large amount of urea, 2.6 per cent, in the blood and other tissues of the normal dog-fish. Quinton ('90) confirmed this statement of von Schroeder's. Rodier ('00) found at Arcachon on the southwest coast of France that the Δ 's of the blood serum of different species of elasmobranchs were similar, although slightly lower than that of the sea-water in which they lived. The pericardial, peritoneal and uterine liquids had the same Δ as the blood serum. He also corroborated the discovery of von Schroeder as to the presence of urea in the blood of elasmobranchs and called attention to its rôle in determining the osmotic pressure of the blood. He found that the bile and urine contained less chlorine than the blood. Fredericq ('04) confirmed Rodier's statement with regard to the rôle of urea in maintaining the osmotic pressure of the blood. He found that if one puts a dog-fish, *Scyllium*, into concentrated or diluted sea-water, equilibrium between the osmotic pressure of the internal medium and the external medium takes place in a short time, due to the withdrawal or addition of water from the blood without involving the dissolved substances of the blood. Garrey ('05) found that the blood of the elasmobranchs from Woods Hole is isotonic with the sea-water and that dilution or concentration of sea-water causes a similar change in the blood of selachians immersed in such modified media, but that death ensues before

the cartilaginous fishes are isotonic with the sea-water. It should be noted here that the Δ of the sea-water at Naples, where Bottazzi worked, is much greater than that at Arcachon and Woods Hole, where Rodier and Garrey respectively worked, and yet the blood of the elasmobranchs from all three regions is approximately isotonic with the surrounding medium. Bottazzi ('08) came to the conclusion that the urea, found in such large quantity in the blood, is formed by the muscles. Baglioni ('05) corroborated von Schroeder's '90 statement with regard to the urea in selachian blood. He also found that the elasmobranch heart would continue to beat if filled with a solution of equal parts of urea and sodium chloride, to which a trace of calcium salt was added. Dakin ('08) found marked changes in the osmotic pressure and chlorine content of the blood of the dog-fish when the animal was immersed in fresh water. One of his general conclusions is that the limiting membranes of the body are impermeable to salts and that the changes observed in the blood are due to variations in the relative amount of water. The limiting membranes of the body are semi-permeable. Hyde ('08) found that injection of solutions of sodium, calcium, potassium and magnesium salts in different degrees of dilution produced changes in the blood pressure and the respiratory and cardiac activity.

OSMOTIC PRESSURE OF THE BLOOD OF *Mustelus canis* UNDER NORMAL CONDITIONS

Emphasis is often placed upon the constant value of the osmotic pressure of mammalian blood. Yet Findlay ('05) calls attention to the fact that there are diurnal variations in the osmotic pressure of human blood. Thus he gives the Δ of human blood at 9 A. M. as 0.535° ; at 12 M. as 0.558° ; at 1.30 P. M., after dinner, as 0.585° , and at 5.45 P. M. as 0.528° . Bottazzi ('06) found that the Δ of the blood and body fluids of marine invertebrates in the neighborhood of Naples fluctuated between 2.195° and 2.36° . He also found a similar range in the depression of the freezing point of the sea-water. Rodier ('00) working at Arcachon on the southwest coast of France found that the Δ of the waters from the laboratory basin varied between 1.87° and 1.95° , while the water from the ocean itself was more constant, having Δ 's ranging from 2.05° to 2.09° . Rodier in describing the Bay of Arcachon said: "Its waters have a density, salinity and osmotic pressure always less than sea-water, and varying with the season, height of tide, place from which the water was taken, depth of water and time of day." Rodier found that the freezing point of the blood serum of different species of selachians was near to that of their sea-water medium, although in many cases it was 0.04° to 0.05°

lower. He concluded that they had not become acclimated to the more dilute bay water. Bottazzi ('06) found that the Δ of the blood of *Scylium stellare* varied from 2.31° to 2.42° . He recorded the Δ of the blood of *Trygon* as 2.378° , while Mosso recorded it as 2.44° . Bottazzi ('06) found the mean Δ of the blood of elasmobranchs at Naples to be 2.356° , although the mean Δ of the sea-water was 2.29° . Yet Bottazzi concluded that the osmotic pressure of the blood of cartilaginous fishes is similar to that of the marine invertebrates in being identical with that of the sea-water. Garrey ('05) noted variations in the Δ of the sea-water at Woods Hole and variations also in the Δ of the blood of elasmobranchs. The mean Δ of sea-water was 1.82° , while that of the elasmobranchs he studied was 1.88° .

I have noted at different times the following Δ 's of the sea-water in the laboratory of the Fisheries station at Woods Hole, namely: 1.76° ; 1.78° ; 1.79° ; 1.80° ; 1.83° ; 1.855° ; 1.87° . The average of these is $1.81^{\circ}+$. The Δ 's of eighty specimens of *Mustelus* taken from the sea-water of the laboratory basin at various times proved to be as follows:

TABLE I.—Distribution of the freezing point of the blood of eighty specimens of *Mustelus canis*

Number of specimens	Δ	Number of specimens	Δ	Number of specimens	Δ
1	1.71°	7	1.83°	6	1.90°
1	1.74	7	1.84	5	1.91
1	1.76	5	1.85	9	1.92
1	1.78	4	1.86	6	1.93
1	1.79	4	1.87	2	1.95
5	1.80	6	1.88	1	1.99
3	1.81	2	1.89	1	2.03
2	1.82				

The mean depression of freezing point of the blood of the eighty specimens is 1.869° . Garrey recorded a mean value of 1.88° . But the mean Δ does not give a proper conception of the fluctuation in the osmotic pressure of the blood. It is possible that the extremes of this series represent abnormal fishes. Greene ('05) found a decrease of 32 per cent from the normal Δ of the blood of the Chinook salmon in the case of an old weak male and attributed this extreme variation to the pathological condition of the specimen. On referring to the above table, it will be seen that the greater number of Δ 's range between 1.80° and 1.93° . The distribution of Δ 's between these points is, with the exception of those at 1.92° , quite uniform. The average Δ is just about midway between these two points. There are about as many Δ 's one side of the mean point as on the other side. The mean Δ of *Mustelus* blood is $.05^{\circ}$ lower than

the sea-water in which it lives. It has already been noted that Rodier ('00) observed the same fact in connection with the elasmobranchs at Arcachon. The observations of Bottazzi ('06) reveal the same relationship. Finally, Garrey's '05 data agree nearly with mine.

The small difference between the Δ of the blood and that of sea-water is important in that the molecular concentration of the blood of elasmobranchs is only approximately equal to that of the sea-water. According to the above table, the blood of *Mustelus* can pass with entire safety through a range of at least 0.15° in its osmotic pressure.

CHANGES IN THE OSMOTIC PRESSURE OF THE BLOOD DUE TO ALTERATIONS IN THE DENSITY OF THE EXTERNAL MEDIUM

PRELIMINARY STUDY

It has been shown by a number of investigators that the osmotic pressure of the internal body fluids of the marine invertebrates depends upon the molecular concentration of the surrounding medium. Fredericq ('04), Garrey ('05) and Dakin ('08) have shown that this is true to a certain degree of the elasmobranchs. Fredericq concluded that a new equilibrium was established when he put *Scyllium* into diluted or concentrated sea-water. For example, he put *Scyllium* into diluted sea-water having a Δ of 1.67° for twenty-seven hours, at the end of which time the Δ of its blood serum was 1.70° . Another specimen was put into concentrated water having a Δ of 2.72° for twenty-four hours, when the Δ of the blood was 2.70° . Garrey ('05) found that the blood of *Mustelus canis*, though normally having a mean Δ of 1.88° , changed to 1.45° after an hour's immersion in fresh water. Dakin ('08) found that when the spiked dog-fish, *Acanthias vulgaris*, and the skate, *Raia clavata*, were put into fresh water, there was a considerable fall in the osmotic pressure of the blood. The mean Δ of these forms was 1.90° . In the four hours during which the dog-fishes were in fresh water, the Δ of the blood changed to 1.435° , showing a rise in the freezing point of 0.465° from the normal condition. The three specimens from which the above results were obtained were nearly dead at the end of the experiment. The change in the blood of the skate was not as great. This form was nearly dead at the end of two hours' immersion in fresh water, at which time the Δ of the blood was 1.645° , showing a rise in the freezing point of $.255^\circ$. In these experiments of Garrey and Dakin, death took place before a new osmotic equilibrium was established. I determined to ascertain whether there was any relation between the duration of immersion in modified solutions of sea-water and the change in the osmotic pressure of the blood. The form used was *Mustelus canis*. As brought into the laboratory, the fish

were placed in a large tank of sea-water. The salt water supply was then shut off and a stream of fresh water was turned into the tank. In a few minutes the water in the tank was fresh. After certain periods of immersion, the specimens were removed and a small quantity of blood was drawn from the caudal artery of each for a freezing point determination. It will be noted in the experiments that follow that the normal Δ of the blood of each animal is not given. But one freezing point determination was made in each case and that at the end of the time of immersion in the experimental medium. It should be borne in mind, however, that the mean Δ of the normal blood of *Mustelus* is about 1.87° . The results of the first experiment are as follows:

TABLE II.—*Change in the freezing point of the blood after various periods of immersion in fresh water*

(Δ of fresh water = 0.025°)		
Specimen	Immersion time in minutes	Δ of blood
1	35	1.62°
2	40	1.565
3	60	1.585
4	60	1.610
5	75	1.495
6	90	1.54

Individual changes in the freezing point of the blood are not the same for the same time of immersion. In a general way, however, the osmotic pressure becomes progressively less as the time of immersion increases.

I next concluded to ascertain the relation of change in the freezing point of the blood to solutions less dilute than fresh water. In the second experiment a solution of one-half sea-water and one-half fresh water was employed. The Δ of this solution is about 0.90° . The results are as follows:

TABLE III.—*Showing the change in the freezing point of the blood after various periods of immersion in one-half sea-water and one-half fresh water*

Specimen	Immersion time in minutes	Δ of blood
1	50	1.77°
2	75	1.705
3	100	1.685
4	200	1.595
5	245	1.555

In the third experiment a solution of three-fourths sea-water and one-fourth fresh water was used. The following results were obtained. The Δ of this solution is about 1.35° .

TABLE IV.—*Showing the change in the freezing point of the blood after various periods of immersion in three-fourths sea-water and one-fourth fresh water*

Specimen	Immersion time in minutes	Δ of blood
1	30	1.77°
2	60	1.74
3	100	1.73
4	230	1.64

Both solutions cause a rise in the freezing point of the blood. Yet the rise is greater in the more dilute solution. On comparing the effects of the two solutions, it is seen that the same changes in the freezing point are produced in a shorter time in the second solution than in the third solution. A similar effect is produced in still less time in the first solution, fresh water, than in the second one, which is one-half fresh water and one-half sea-water.

The effect of concentrated solutions of sea-water was next measured. Two such solutions were employed: one with a specific gravity of 1.035 and a Δ of 2.60° ; the other with a specific gravity of 1.040 and a Δ of 3.15° . The results were as follows:

TABLE V.—*Showing the change in the freezing point of the blood after various periods of immersion in concentrated solutions of sea-water*

Solution A—Sp. Gr. = 1.035 $\Delta = 2.60^{\circ}$		
Specimen	Immersion time in minutes	Δ of blood
1	30	2.075°
2	50	2.115
3	75	2.185
Solution B—Sp. Gr. = 1.040 $\Delta = 3.15^{\circ}$		
Specimen	Immersion time in minutes	Δ of blood
1	35	2.10°
2	45	2.16
3	85	2.175

In both of the solutions more concentrated than sea-water there is a lowering of the freezing point of the blood, an effect which is just the opposite of that produced by fresh and dilute solutions. The initial effect is greater in the more concentrated solution, although the final effect is about the same.

Although in each of the five experiments the normal Δ of each specimen as taken from sea-water is not known, the results indicate that the degree of change in the osmotic pressure of the blood depends upon the molecular concentration of the external medium. The results differ from those of Fredericq, in that they show that the osmotic pressure of the blood does not become equal to that of experimental media that differ markedly from the medium to which the animals are normally adapted. Attention is again called to the different degree to which the individual animals respond to modifications in the concentration of the external medium. Some die sooner than others in these abnormal media. Hyde ('08) observed that the effects of operation varied in different skates. For example, Hyde noted that when the same operation was performed upon two animals apparently in every respect alike, in the one case the effects might be momentary, while in the other they might be severe and prolonged.

CHANGES IN THE OSMOTIC PRESSURE OF THE BLOOD FROM THE NORMAL CONDITION UNTIL NEAR DEATH IN FRESH WATER AND CONCENTRATED SEA-WATER

Green ('05) found that the chinook salmon, *Oncorhynchus tshawytscha*, in its migrations to the head waters of rivers for spawning, underwent a permanent decrease of 17.6 per cent in the concentration of its blood and yet was able to carry on with vigor the activities of its muscular and nervous system. How far may this decrease proceed before death takes place? He found that the blood serum of an old weak male salmon showed a decrease of 32 per cent from the mean Δ of the blood serum of normal salmon. This represents the maximum of dilution of which the blood is capable while still maintaining life. I concluded to investigate this question in the case of the dog-fish, *Mustelus*, and at the same time to study the progressive osmotic changes of the blood from normal life to death in fresh water and concentrated sea-water. Cessation of breathing was taken as an index of death.

The following technique was employed: The spinal cord of the animal was exposed from the dorsal aspect, at the junction of the caudal fin with the trunk of the body. In this way no large blood vessel was interfered with. The cord was then destroyed by a probe as far forward as the an-

terior dorsal fin. Hyde ('08) has shown that all the centers governing respiration in the skate, though of a segmental nature, are located in the medulla. Since in the above operation only the posterior two-thirds of the cord was destroyed, the nervous structures that govern respiration were not affected.

After the cord was destroyed, the tail was removed, the caudal artery and vein being thus exposed. Blood was then taken for the determination of its freezing point. After this, the caudal artery was closed with a small wooden plug covered with absorbent cotton. The animal with the exception of the posterior part of the body was then placed in the tank containing the experimental solution. After the desired time, a second sample of blood was taken for a second determination of its freezing point. The difference between the first and the second was a measure of the change in the osmotic pressure of the blood of the particular animal for the given time and the given solution. In a number of cases as many as six samples of blood, usually about 5 c. c. each, varying with the size of the fish, were taken from one specimen. The blood was drawn into a small beaker and placed in an ice bath until the caudal artery of the fish could be closed and the fish could be transferred back to the water. The common freezing tube with the side neck for the insertion of an ice crystal was not used on account of the large amount of blood that would thus be necessary for each determination. A test tube with a smaller diameter was used instead. Duplicate determinations of the freezing point of the blood and distilled water demonstrated that the error due to undercooling must have been small. The experiment was repeated in a number of cases with uniform results, as will be shown later. Several clean dry test tubes were kept at hand in order to facilitate the determination of the freezing point of a number of samples in the shortest space of time. I found that about fifteen minutes were required for all the steps in the making of a single determination. On account of necessary interruptions, it was not possible to make the time intervals equal in all cases.

The whole blood, including corpuscles and plasma, was used in the experiments that follow. Hamburger ('95), Roth ('99) and others have asserted that the corpuscles are inert in determinations of the freezing point. Moore ('08) found that the corpuscles of pig's blood had a Δ of from 0.02° to 0.03° lower than that of the serum. Since in all the following experiments Δ was obtained in the way already indicated, the error due to the presence of corpuscles would be approximately constant in cases where the corpuscles were not laked. It would have been practically impossible to make the frequent determinations of Δ in these experiments, had I stopped in each case to defibrinate and centrifuge each

sample of blood. The results are as useful for purposes of comparison as if the blood had first been defibrinated and then centrifuged. Time was saved by omitting these procedures and I believe that the results are as satisfactory. The actual pressure in atmospheres can be easily found by

$$\text{multiplying } \Delta \text{ by } \frac{22.4}{1.85} (= 12.108).$$

EFFECT OF FRESH WATER

After the first sample of blood was taken, the animal was placed in a tank of sea-water, into which fresh water was then run, so that in a few minutes the water in the tank was fresh. The results of this experiment were obtained from a series of ten fishes, six males and four females, ranging from 61 to 82 centimeters in length, and are shown in Table VII.

TABLE VII.—Changes in the freezing point of the blood of *Mustelus canis* after immersion in fresh water until nearly dead

Sex	Length in cm.	Weight in grams	Immersion time in minutes	Δ of blood	Change in Δ of blood
♀	79	1588	0	1.93 °	0.000 °
			15	1.905	0.025
			30	1.805	0.125
			45	1.705	0.225
			60	1.630	0.300
			73	1.600	0.330
♂	64	822	0	1.81	0.000
			25	1.805	0.005
			60	1.530	0.280
			80	1.380	0.430
♀	69	1021	0	1.88	0.000
			40	1.73	0.150
			65	1.64	0.24
			90	1.435	0.445
♀	61	652	0	1.87	0.000
			20	1.81	0.06
			45	1.64	0.23
			60	1.50	0.37
♂	82	2211	0	1.880	0.000
			15	1.855	0.025
			30	1.79	0.09
			45	1.71	0.17
			60	1.61	0.27
♂	74	1134	0	1.880	0.000
			20	1.84	0.04
			40	1.74	0.14
			60	1.64	0.24
			80	1.38	0.50

TABLE VII.—*Changes in the freezing point—(Continued.)*

Sex	Length in cm.	Weight in grams	Immersion time in minutes	Δ of blood	Change in Δ of blood
♀	80	1687	0	1.890	0.000
			35	1.76	0.13
			55	1.605	0.285
			70	1.53	0.36
			85	1.39	0.50
♂	77	1502	0	1.900	0.000
			20	1.84	0.06
			40	1.74	0.16
			55	1.59	0.31
♂	79	1460	0	1.850	0.000
			15	1.81	0.04
			30	1.76	0.09
			45	1.635	0.215
			65	1.50	0.35
			75	1.40	0.45
♀	76	1304	0	1.920	0.000
			15	1.87	0.05
			40	1.74	0.18
			55	1.63	0.29
			70	1.47	0.45
			80	1.44	0.48

In averaging the results, we may divide the time into five periods of twenty minutes each, the first twenty minutes of immersion constituting the first period and so on. The average change during each period of immersion is as follows:

1st twenty minutes = $+0.050^{\circ}$
 2nd twenty minutes = $+0.133$
 3rd twenty minutes = $+0.265$
 4th twenty minutes = $+0.400$
 5th twenty minutes = $+0.470$

The average of the ten maximum determinations is $+0.408^{\circ}$.

As was found in the series of experiments described on page 9 there are indications here also of individual variations in the reaction of the fishes to the changed environment. Figure 1 is a curve which represents the course of the change in the depression of the freezing point and therefore a fall in the osmotic pressure of the blood from the beginning to the end of the experiment. This curve is derived from the values computed for each of the twenty minute periods. Certain features of this curve may be here pointed out. There is a slow change at the beginning of the experiment. This continues during the first two of the five periods of immersion. There is then a change in the slope of the curve, indicating

more rapid changes in the osmotic pressure of the blood. Toward the end of the time, less rapid changes are again indicated. The ordinate which determines the last part of the curve is the average of but two determinations, because most of the animals died before the immersion of a hundred minutes. The ordinate at D more correctly represents the average condition at death. That part of the curve from N to D represents graphically the course of the change in the freezing point of the blood from the normal condition until near death in fresh water. It may be thought that the initial slowness of the changes in the osmotic pressure of the blood is due to the fact that the water is changing from salt to fresh during this period. The slowness, however, continues longer than the time required for the

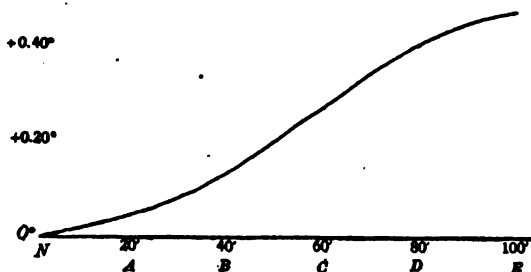


FIG. 1.—Change in Δ of blood of *Mustelus* due to immersion in fresh water until death

the animal. From this point of view, the second part of the curve might indicate the passage of dissolved substances such as salts out from the blood through the limiting membranes of the body into the water outside while the outside water continued to pass into the blood. This would mean, of course, profound changes in the physico-chemical constitution of the organism. Dakin ('08) found that the maximum change in the freezing point of the blood of three specimens of *Acanthias vulgaris* after immersion in fresh water until near death was 0.465° . Garrey found the maximum change in the freezing point of the blood of one *Mustelus* to be 0.37° . My observations range from 0.27° to 0.50° . That the magnitude of the change is not due to the amount of blood taken is shown from the records of specimens 1 and 2. The maximum change in case of No. 1 is $.33^{\circ}$, while that of No. 2 was $.43^{\circ}$, though six samples of blood were taken from the first specimen, while but four samples were taken from the second specimen. Other cases of the kind can be found.

EFFECT OF A CONCENTRATED SOLUTION OF SEA-WATER

tained. The procedure was in the main as before. The tank in which the specimens were placed after the operation contained about twenty-four liters of sea-water. To increase the amount of salts in solution in this sea-water, about 500 grams of sea-salt were dissolved in a jar containing eight liters of sea-water. This was placed above the tank. After the normal sample of blood was obtained, the specimen in each case was placed in the tank of sea-water and the concentrated solution from the jar was at once run into the tank at one end, the overflow running out at the other end. At the same time, the various samples of blood were obtained for the determinations of the freezing point, the specific gravity of the water in the tank was taken. On the whole, the specific gravity of the solution was 1.034+. Its Δ was about 2.60° . The Δ of the sea-water was about 1.82° and its specific gravity, 1.025. An analysis of the chlorides in both sea-water and in water of the concentration attained at the end of each of these experiments showed that the latter contained about 33 per cent more salts than sea-water. The water in the tank reached this concentration in about fifteen minutes after each experiment began. The results are given in Table VIII. Data with regard to eleven specimens are shown, seven females and three males, ranging in length from 67 cm. to 84 cm. The sex of one animal was not recorded.

TABLE VIII.—Changes in the freezing point of the blood of *Mustelus canis* after immersion in a concentrated solution of sea-water until near death.

Sex	Length in cm.	Weight in grams	Immersion time in minutes	Δ of blood	Change in Δ of blood
♀	80	1531	0	1.84°	0.000°
			17	1.90	0.06
			30	1.96	0.12
			48	1.99	0.15
			65	2.06	0.22
			77	2.08	0.24
♀	80	1361	0	1.84	0.000
			20	1.93	0.09
			35	2.01	0.17
			50	2.05	0.21
			65	2.11	0.27
			80	2.15	0.31
♂	75	1247	0	1.88	0.000
			25	1.94	0.06
			40	2.00	0.12
			55	2.07	0.19
			75	2.10	0.22
♀	67	950	0	1.80	0.000
			15	1.87	0.07

TABLE VIII.—Changes in the freezing point—(Continued.)

Sex	Length in cm.	Weight in grams	Immersion time in minutes	Δ of blood	Change in Δ of blood
♂	76	1332	0	1.84	0.000
			15	1.86	0.02
			30	1.91	0.07
			45	1.99	0.15
			60	2.02	0.18
♂	76	1417	0	1.89	0.000
			10	1.95	0.06
			30	2.01	0.12
			45	2.07	0.18
			60	2.09	0.20
♀	84	1531	0	1.83	0.000
			20	1.92	0.09
			40	1.96	0.13
			60	2.01	0.18
			80	2.08	0.25
♀	74	1162	0	1.93	0.000
			12	2.00	0.07
			25	2.07	0.14
			40	2.11	0.18
			55	2.17	0.24
♀	79	1446	0	1.94	0.000
			20	2.02	0.08
			35	2.07	0.18
			45	2.15	0.21
			65	2.15	0.21
	75	992	0	1.92	0.000
			15	2.02	0.10
			30	2.06	0.14
			50	2.11	0.19
			65	2.18	0.26
♀	76	1219	0	1.90	0.000
			15	1.96	0.06
			35	2.01	0.11
			60	2.08	0.18
			75	2.15	0.25

Dividing the above time into four periods of twenty minutes each and averaging the change in the freezing point of all the specimens for each period, we have the following values:

1st twenty minutes = 0.074°

2nd twenty minutes = 0.125

3rd twenty minutes = 0.190

4th twenty minutes = 0.260

The average of the eleven maximal changes is 0.24°. Figure 2 is a curve which represents the course of the change in the blood from the

normal condition until near the death of the animal in the above concentrated solution. Since the curve shows a progressive lowering of the freezing point of the blood, it should be interpreted as showing an increase in the osmotic pressure of the blood. There is a slight falling off in the effect after an initial sudden change in the freezing point. Toward the end of the time of immersion the change is more rapid again.

There is good evidence for believing that the dog-fishes in their migrations up and down the coast wander into brackish waters. The organism must be adapted therefore to withstand a moderate amount of decrease in the density of the external medium. Under natural conditions, however, the organism is never subjected to such a concentrated solution as was used in the present experiment. The concentrated salt solution may act

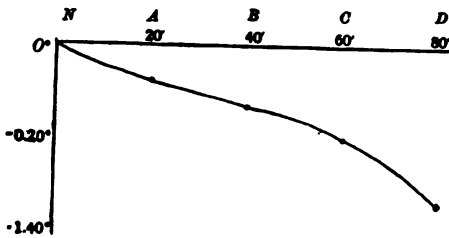


FIG. 2.—Change in Δ of blood of *Mustelus* due to immersion of fish in a hypertonic solution of sea-water until death.

as a chemical stimulus upon the arterioles of the gills, causing them to dilate, and thus bringing about a greater influx of blood to the gills, from the capillaries of which the blood would lose water rapidly by osmosis. After the initial stimulus, the arterioles would recover their tone, there would be a decreased amount of blood

sent to the gills and the loss of water would be retarded. The more rapid increase in Δ toward the end of the period is evidently an index of greater changes in the physico-chemical constitution of the organism.

The above results as to the effect of fresh water and concentrated sea-water on the osmotic pressure of the blood show that, at the time of death in fresh water, there is an average rise in the freezing point of the blood of 0.41° and, at death in the above concentrated solution, a fall of 0.24° , i. e., in the osmotic pressure a reduction of 21.9 per cent and an increase of 12.8 per cent respectively. The values probably represent the lethal limits of departure from the normal constitution of the blood within which protoplasmic activities of this form take place. I must differ from Fredericq and others who would classify the elasmobranchs with the marine invertebrates as to the osmotic relations of their body fluids to the

elasmobranchs and modifications in the molecular concentration of the sea-water. Fresh water has a Δ of about 0.025° . This is about 1.795° less than that of sea-water. The concentrated solution had an average specific gravity of about $1.034+$. The Δ of such a solution was about 2.60° , which is 0.78° greater than that of sea-water. Since the fresh water produced an average rise in the freezing point of the blood of 0.41° , what would be the amount of change in the freezing point of the blood in the concentrated solution if the change in the blood depends upon the change in the molecular concentration of the external medium? We can formulate the following proportion: $1.795^\circ : 0.41^\circ :: 0.78^\circ : X$, where X should equal the change in the blood due to the concentrated solution should the above relation hold true. X equals 0.177° or approximately 0.18° ; but the observed maximum change in the concentrated solution was 0.24° . There is a difference between the two values of 0.06° . This would indicate that the relation is only roughly if at all proportional. If the changes took place to a different degree or in a different manner in the two solutions, of course any close relationship would be modified.

Furthermore, do these results show any relation between the degree of change in the freezing point of the blood and the time of immersion? In the fresh water experiment, eight records were taken between 40 and 45 minutes from the beginning. The average time was about 42 minutes. The average time of immersion of all ten fishes was 74 minutes. The average final change in the Δ of the blood was 0.41° . Therefore in the following proportion,—74 min. : 42 min. :: $0.41^\circ : X$, X should have approximately the same value as the Δ actually observed at the end of the 42 minute period. X equals 0.23° , the theoretical degree of change in Δ . The observed change in the Δ of the blood of the eight specimens after 40 to 45 minutes' immersion in fresh water was $0.18+$, showing that the observed change lacked $0.04+$ of being as great as the calculated change.

The average time of immersion in the concentrated solution was 69 minutes. Six determinations were made at about 42 minutes from the beginning of the experiment. If the time relation holds in this case, then X in the following proportion should be similar to the observed change in Δ at the end of the 42-minute period: 69 min. : 42 min. :: $0.24^\circ : X$. But X equals 0.146° . The observed change in 42 minutes was 0.16° . One might conclude from the above considerations that we were dealing here with purely physico-chemical phenomena. It would be hazardous, however, to make any sweeping assertions. If we compare the

are so many and to such a degree unknown, that although, in the final analysis, the phenomena must be physical and chemical, we are not justified in maintaining that the relations are definitely quantitative.

Figure 3 represents in a graphic manner the relation of the osmotic pressure of the blood to the concentration of the external medium as based upon the conception of a proportional relation existing between the two. The abscissas represent freezing point determinations. The ordinates represent specific gravities of different solutions of sea-water. Pure

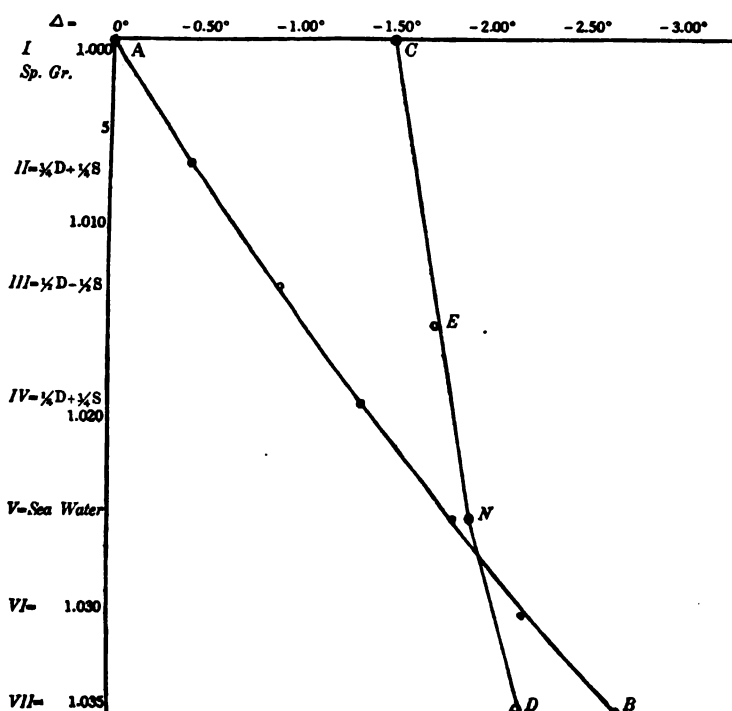


FIG. 3.—Relation of the Δ of blood to Δ of different solutions of sea-water. Curve A-B = Δ 's of solutions. Curve C-D = Δ 's of blood

water has a Δ of 0.00° and a specific gravity of 1.000. The curve A—B represents the freezing point of different dilutions of sea-water. This curve is constructed from freezing point data obtained from seven different dilutions of sea-water. These were as follows: I, pure water; II, three-fourths pure water plus one-fourth sea-water; III, one-half pure water plus one-half sea-water; IV, one-fourth pure water plus three-fourths

1.034+. The curve C—D represents the freezing point of the blood at the different concentrations represented by the curve A—B. It is constructed by drawing a line through the following points: C = the Δ of the blood at the death of the organism in fresh water; N, the Δ of normal blood; D, the Δ of the blood at the death of the animal in the concentrated solution, having a specific gravity of 1.034+ and a Δ of 2.60° , the effect of which has been described in this section of the paper; E, the Δ of blood of *Squalus acanthias* in harbor water which has a Δ of about 1.00° .

A further account of this is given later (on page 31). That the operation of destroying the cord did not modify the results is strongly indicated by the following instance: A large *Mustelus canis* was operated on in an attempt to collect a sample of its urine. The spinal cord was destroyed in the manner already indicated. The abdominal cavity was opened, the rectum was ligated and a large glass tube was fastened in the cloaca. The animal was then placed on a support in the sea-water in such a way that the head as far back as the last gill slit was under water. The abdominal incision was closed and the surface of the body was kept moist with a cloth wet with sea-water. At the end of twenty-four hours the fish was still alive and breathing normally. When the pericardium was opened, the heart was seen to be beating regularly. Figure 4 is a record of the respiration at the end of twenty-four hours, the time record indicating intervals of two seconds. Although the experiment was a failure as far as its primary purpose was concerned, it proved that the above operation in itself is no cause of immediate death. Sheldon ('09) has found that *Mustelus* may live for a week after a similar destruction of the cord. Parker ('10) has called attention to "the ease with which this fish resists the adverse effects of operations."

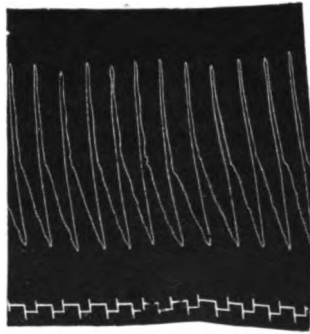


FIG. 4. — Respiratory movements in *Mustelus*, 24 hours after destruction of spinal cord.

In a series of earlier experiments, the results of which are given in Table VI, on the effect of immersion in fresh water on the freezing point of the blood, I first defibrinated the blood then centrifuged it, and used

blood was drawn after they had been immersed for about an hour. The results were as follows:

TABLE VI.—*Showing the depression of the freezing point of the serum of Mustelus in salt water and after immersion in fresh water for one hour*

Serum from normal fishes		Serum from fishes immersed in fresh water one hour	
No. specimen	Δ	No. specimen	Δ
1	1.920°	1	1.580°
1	1.960	4	1.460
2	1.805	2	1.595
2	1.950	2	1.595
1	1.947	2	1.540
Average, 1.914°		Average, 1.554°	

The average rise in the freezing point of the serum of these dog-fish after immersion in fresh water for an hour is thus seen to be $+0.36^\circ$.

CHANGES IN THE OSMOTIC PRESSURE OF THE BLOOD BROUGHT ABOUT BY A RETURN TO SEA-WATER AFTER IMMERSION IN FRESH WATER OR CONCENTRATED SEA-WATER

The above experiments on the effects of diluted and concentrated solutions of sea-water indicate that to cause a decrease in osmotic pressure with the diluted solutions there must be currents outward through the limiting membranes of the body; to cause an increase with concentrated solutions there must be currents inward. Is it possible to demonstrate these two effects in the same individual? If reversibility is possible, then after a fall in osmotic pressure resulting from immersion in a diluted solution of sea-water, the original pressure should apparently be gained when the animal is returned to normal sea-water. The experiments reported in Table IX were carried out to test this possibility.

TABLE IX.—*Effect on the blood of transference of Mustelus from sea-water to fresh water followed by subsequent return to sea-water*

Sea-water	Fresh water			Sea-water			
Normal Δ of blood in degrees	Duration of immersion in minutes	Δ of blood	Change from normal	Duration of immersion in minutes	Δ of blood	Change from normal	Amount of reversal
1=1.835	35	1.620°	+0.215°	25	1.685°	+0.15 °	0.065°
2=1.895	55	1.655	+0.240	50	1.785	+0.115	0.125
3=1.875	30	1.675	+0.200	50	1.760	+0.115	0.085
4=1.905	25	1.665	+0.240	100	1.785	+0.120	0.120

It is clear that, after immersion in fresh water, we get as before a rise in the freezing point of the blood. After the return to sea-water, the Δ is lowered and the osmotic pressure is increased again; but the normal osmotic pressure of the blood is not regained, even though the return to sea-water is as long or even longer than the sojourn in fresh water. This is shown in the case of the fourth specimen; for after 25 minutes in fresh water the freezing point had been raised 0.24° above normal, but when the fish had been returned to sea-water for 100 minutes the freezing point was still 0.12° above normal. Figure 5 shows the changes in the Δ of the blood of this specimen. The fish was in fresh water from F to F' and in sea-water from F' to S. The base line represents the normal Δ ; the abscissas, time in minutes, and the ordinates, the rise in the freezing point of the blood. At first one might conclude from these experiments that the limiting membranes were not as permeable in one direction as the other. A second experiment of this nature will be de-

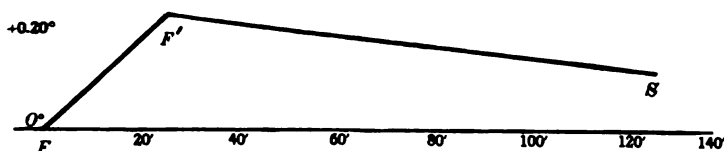


FIG. 5.—Changes in Δ of blood of *Mustelus* due to immersion in fresh water followed by return to sea-water

scribed. In this case, the mixed blood of the two specimens was used for the determination of the normal Δ , 1.895° . After 75 minutes' immersion in fresh water, there was noted a rise in the freezing point of the mixed blood of 0.245° . Both specimens were then returned to sea-water and one died soon after. A determination was made from the blood of the other 225 minutes after the return, and its Δ was 0.05° above the normal Δ . Although there was an apparent return to the normal condition, the animal was injured in some way, for it died soon after. In fact, it is not quite correct to assume that the normal condition of the blood was regained for the last figure given, i. e., 0.05° is obtained by subtracting the final Δ of the blood of this fish from the Δ of the mixed blood of this fish and the other which died earlier. The number of molecules and ions in solution in the blood had decreased after immersion in fresh water. Certain parts normally present had escaped into the surrounding medium. The return of the organism to its normal medium did not suffice for the return to the blood plasma of the normal quantitative relation of parts in solution.

Concentrated solutions were also tried. Two such experiments will be

described. In the first, three dog-fishes were used. The Δ of the combined blood of the three was 1.92° . They were then placed in a concentrated solution of sea-water having a Δ of about 2.60° for forty minutes, at the end of which time the Δ of the mixed blood from the three was 2.11° , the freezing point having fallen 0.19° . Then the specimens were returned to sea-water for eighty minutes, when Δ was 2.04° , showing that although the freezing point had risen 0.07° , it still lacked 0.12° of being normal. In the second experiment, three dog-fishes were also used. The normal Δ of their mixed blood was 1.87° . They were placed for sixty minutes in a tank containing a concentrated solution of sea-water having a Δ of about 2.15° . At the end of this time the Δ of their mixed blood was 2.00° , showing a fall in the freezing point of 0.13° . The three specimens were then returned to a concentrated solution having a Δ of 2.60° for sixty minutes more, at the end of which time the Δ of their combined blood was 2.18° , showing a total fall in the freezing point of the blood of 0.31° . Sea-water was then run into the tank for two and one-half hours, when the value of the Δ of the blood was 1.98° ; that is in the two hours and a half after the return to sea-water the freezing point of the blood rose 0.20° , but was still 0.11° short of its value at the beginning of the experiment. Thus with neither a hypotonic nor a hypertonic medium did the organisms regain the normal Δ after the return to sea-water, even though they were kept in the sea-water as long or even longer than in the diluted or concentrated solution.

One other experiment of this nature will be referred to briefly. A somewhat small stream of concentrated sea-water was passed into the mouth and out through the gills of a large female dog-fish for 45 minutes. The Δ of its blood fell 0.09° . The small size of the stream possibly explains the small change in Δ . A stream of fresh water was then turned on gradually and Δ was again taken 60 minutes later. Δ proved to be 0.16° above its value in the concentrated solution and was even higher by 0.07° than the normal. The fish was then returned to sea-water for 60 minutes when Δ was 0.03° lower than the normal. In this case we have evidence of an increase in the osmotic pressure of the blood due to a concentrated external medium. A fall in the osmotic pressure results when the organism is subjected to a dilute external medium, after which it rises to the normal condition when the animal is returned to sea-water.

having an inside diameter of about a centimeter. It seems to me that the normal Δ was regained in this case, because the external media produced but a small degree of departure from it. It is interesting to note that the maximum change produced in Δ is about equal to the normal range in Δ of normal dog-fish blood as described in the first section of this paper. The results with the other fishes indicate, however, that osmotic phenomena are complicated by the presence of other factors.

RÔLE OF THE GILLS IN THE MODIFICATIONS

Considerable difference of opinion exists as to the part of the body that is concerned in the osmotic changes in the blood brought about by changes in the osmotic pressure of the surrounding medium. As stated above, there are three structures that may be the seat of this phenomenon, namely, the skin of the body, the lining of the alimentary tract and the gill membranes. Any one or all of these structures may be conceived to share in the above processes. The surface of the body of the dog-fish is covered with a closely associated system of dermal plates forming, with other structures of the skin, a tough coat through which it would appear that fluids could pass with the greatest difficulty if at all. The cells of the intestinal tract are known to exert a selective action on materials present in the intestine, and therefore we should expect that solutions more or less concentrated than sea-water which would possibly accompany the swallowed food would be passed out through the cloaca before osmotic changes of any account would take place. Furthermore, my observations indicate that the œsophagus and the cloacal aperture are kept closed during the greater part of the time, and are probably opened only during the taking in of food and the getting rid of waste. Therefore the wall of the gut would not ordinarily be exposed to solutions differing in density from that of sea-water, even though the whole fish were entirely immersed in such solutions.

The gills, however, are always freely exposed to the external medium. Each gill filament contains a fine capillary loop composed of an afferent vessel and an efferent vessel supported by connective tissue. Covering the capillary apparatus is an extremely thin epithelial membrane, so that there are but two thin layers of cells between the water and the blood stream, namely, the gill membrane and the endothelial wall of the capillary. If the rich capillary supply of the gills be taken into account, there

The following views have been maintained with regard to this: Bert ('71) gave a minute description of the death of a fresh water fish in salt water. He described the gills as changing from bright red to dark red in color, and said that the congested condition of these membranes permitted the blood to transude through them. He found the corpuscles to be crenated, shriveled and piled up in masses in the capillaries. A tench suspended in a vessel of sea-water lived a long time if the head was kept out of the sea-water and the gills were bathed with fresh water. Fredericq ('04) stated, "I can in a short time change the proportion of salts in the blood of *Carcinas manas*, even to doubling the quantity, if I bring the animal into water more salty than sea-water. This is due to a peculiarly modified epithelium of the gill membranes by which substances dissolved in the water can go through the gills easily." With regard to the fishes Fredericq said, "Les vertèbres aquatiques des poissons se comportent tout differement. Chez eux, la branchie, si permeable aux echanges gazeux de la respiration, semble au contraire constituer une barrier presque infranchissable aux sels dissous dans l'eau de mer. La sang des poissons de mer n'est guère plus sale, au gout, que le sang des poissons d'eau douce." Quinton ('00), however, held the view that salts as well as water can pass through the external surface membranes of marine animals. In a later investigation by Bottazzi and Enrique ('01), it was shown that the stomach wall of the mollusk, *Aplysia*, is normally impermeable to salts. They concluded that the stomach wall is a semi-permeable membrane, allowing the water to pass through but excluding the salts, and proposed the hypothesis that osmotic equilibrium is maintained by the liver, functioning as an organ of resorption. Siedlechi ('03) found that the stickleback, *Gasterosteus*, resisted the effects of sudden transitions from salt to fresh water and *vice versa*. This author held that the structure of the skin amply protects the organism from the effects of changes in the external medium. Schucking ('02) showed that salts left the body of *Aplysia*, though the mouth and anus were ligated. This result, together with those obtained by Quinton and Bottazzi, shows that the surface membranes of *Aplysia* are permeable. Overton ('04) concluded that the skin of amphibians is permeable to water and but slightly permeable to salts. Greene ('05) from his studies of the Chinook salmon inferred that in that species all three structures are impermeable. He

bility of the body wall to water. Garrey suspended *Limulus* so that the gills alone were immersed in a solution of one-half sea-water plus one-half fresh water. A decrease in the osmotic pressure of the blood took place which demonstrated the permeability of the gills.

Sumner ('06) inferred that the structure of the skin of most teleosts was an effective barrier to osmotic exchanges between the tissues of the fish and the external medium. He devised an apparatus by which the body was immersed in a solution of one concentration, while the gills were bathed by water of another concentration. In an experiment with the carp, *Cyprinus carpio*, the body of the fish was immersed in fresh water and sea-water bathed the gills. There was a loss of weight at the end of the experiment. In the second place, the body of this fresh water fish was immersed in sea-water and fresh water was supplied to the gills. The fishes not only continued to live longer than in the first instance, but there was no loss in weight. The result showed that no osmotic changes took place through the body membranes of the carp. When the body of the tautog, *Tautoga onitis*, a marine form, was immersed in sea-water and the gills were bathed with fresh water, the fishes died in from two to three hours. On the other hand, when the gills were supplied with sea-water and the body was immersed in fresh water, the fishes were apparently not affected. These ingenious experiments of Sumner, in which it will be noted that the fishes were not injured, contribute strong evidence for the conclusion that the gills alone are concerned in osmotic changes. Dakin ('08) called attention to the fact, as did Greene, in the case of the salmon, that while the contents of the stomach of the lump sucker are osmotically the same as sea-water, the osmotic pressure of the coelomic fluid, though separated from the cavity of the intestine by a very thin wall, is the same as the osmotic pressure of the blood, which is much less than that of sea-water. He thus proved that the wall of the gut is normally impermeable to salts except in the processes of nutrition and was inclined to the belief that the membranes are semi-permeable.

From different points of view, the evidence indicates that the gills constitute the pathway by which the osmotic changes take place. Sumner alone has attacked the problem directly. Dakin criticised Sumner for not excluding the gut as a possible factor. I concluded to investigate this problem in the case of the dog-fish. The following facts justify Sumner's conclusion:

water. A stream of fresh water was then made to flow into its mouth and out through its gills. At the end of fifty minutes the freezing point of the blood of this specimen, whose gills alone were exposed to the fresh water, was 1.585° . As great a change had taken place in the osmotic pressure of its blood as had taken place in the case of those whose gills, intestinal wall and body surface were all exposed to the fresh water.

The operation on the five following specimens was similar to that on the preceding specimen. A stream of water was not conducted through the mouth, but the fishes were so placed on the support that the head as far back as the fifth gill slit was immersed in the water. In this manner, the oesophagus being ligated and the trunk of the body being out of water, the gills constituted the chief structures exposed to the experimental conditions. More than one determination of the freezing point was made in each case, the conditions of the experiments recorded in Table II being thus duplicated. These five specimens were also left in the fresh water until near death. The following, Table X, shows the results obtained from them:

TABLE X.—*Change in the osmotic pressure of the blood of *Mustelus canis* caused by immersion of the head alone in fresh water*

No.	Length in cm.	Weight in grams	Immersion time in minutes	Δ of blood	Rise in Δ
1	80	1290	0	1.85°	+0.000°
			15	1.68	+0.17
			40	1.52	+0.33
			55	1.37	+0.48
2	77	1148	0	1.92	+0.000
			23	1.75	+0.17
			85	1.965	+0.455
3	79	1134	0	1.87	+0.000
			45	1.72	+0.15
			85	1.56	+0.31
4	86	2041	0	1.93	+0.000
			35	1.91	+0.12
			87	1.59	+0.31
5	80	1616	0	1.925	+0.000
			33	1.835	+0.09
			93	1.475	+0.45

The maximal changes in the freezing point of the blood in the case of the specimens belonging to Table VII, in which the three factors, body surface, intestinal wall and gills were exposed to fresh water, were, respectively: $+0.33^{\circ}$, $+0.43^{\circ}$, $+0.445^{\circ}$, $+0.37^{\circ}$, $+0.27^{\circ}$, $+0.50^{\circ}$,

+0.50°, +0.31°, +0.45°, +0.48°, the average being +0.41°. In the experiments shown in Table X the maximal rises were: +0.48°, +0.45°, +0.31°, +0.34°, +0.45°, the average being +0.407°. There is no marked difference in the changes in the two groups.

After about thirty minutes' immersion of the entire body in fresh water, the average maximum rise in the freezing point of the blood of three dog-fishes was +0.22°. The rise in two other specimens whose gills alone were bathed with fresh water for about the same time was +.247°, an unimportant difference. After the treatment with fresh water, all the specimens were transferred back to sea-water. The freezing point of the blood fell in each case. Moreover, the reverse change in the case of those fishes whose gills alone were exposed to the outside medium was 0.118°, while for those entirely immersed in fresh water the fall was 0.12°.

The average fall in the Δ of the blood of three specimens of *Mustelus* which were entirely immersed for forty minutes in a concentrated solution of sea-water having a Δ of 2.60° was 0.19°. The fall in Δ of one specimen with ligated oesophagus, the body surface out of water and the gills bathed with a hypertonic solution having a Δ of 3.15° for seventy-five minutes was 0.23°. The striking fact here is that the fall was no less in this specimen than in the others, in which all three structures were exposed to the experimental medium. The greater changes in the second case was due to the greater density of the external medium and the longer time of immersion.

In all the experiments described here, it will be noted that as great a change takes place in the osmotic pressure of the blood when the gills are the principal structures exposed to the experimental medium as when the gills, body surface and intestinal tract together are exposed. It is acknowledged that, with the gills, the outside membranes of the head and the lining membranes of the buccal cavity were exposed to the media. The surface membranes of the head are, however, excluded, inasmuch as the non-immersion of a much greater portion of the body surface made no difference in the results. It is extremely improbable that the lining membrane of the buccal cavity takes any part in the above changes, because of its histological structure and blood supply in comparison with the gill membranes. There is but one conclusion to be drawn. Osmotic changes which take place in the blood of *Mustelus canis* when the organism is surrounded by solutions more dilute or more concentrated than sea-water take place through the gill membranes.

OSMOTIC PRESSURE OF THE BLOOD OF AN ELASMOBRANCH TAKEN FROM BRACKISH WATER

The dog-fishes probably migrate. I am informed by Mr. Denyse of the New York Aquarium that the spiny dog-fish, *Squalis acanthias*, is present in New York waters for a time during the latter part of May and the first part of June, and then disappears until the autumn, when it returns to remain until after the New Year. Observations are lacking during the mid-winter, as no fishing is done at that time, but for a number of weeks after the fishing is begun in the spring there is no sign of this species. Mr. Denyse informs me that the smooth dog-fish has been taken at some distance up the Hudson River. It is very probable then that in their migrations up and down the coast they pass the mouths of rivers in which the water must be brackish, especially in the spring time when the rivers are swollen with the spring freshets. Mr. Denyse has kept a daily record of the temperature and salinity of the water from New York harbor for the period from 1903 to 1911. From the monthly averages of that record, published in the Report of the Director of the New York Aquarium ('12), I have computed the average monthly specific gravity of the harbor water for the nine years in question. The results of this calculation are shown in Table XI.

TABLE XI.—Average monthly specific gravity of New York harbor water for the years 1903–1911²

Month	Specific gravity	Month	Specific gravity
January.....	1.0139	July.....	1.0148
February....	1.0135	August	1.0154
March.....	1.0121	September...	1.0155
April.....	1.0100	October.....	1.0148
May.....	1.0120	November...	1.0147
June.....	1.0133	December....	1.0147

Although the migration of fishes is usually stated to be due to a search for better food conditions and for the purpose of spawning, there is a possibility that the non-appearance of *Squalus* in New York waters during the early spring is due to the dilute condition of the water. The density of the water is lowest during April. A considerable rise is noted in May and June, and it is then that these fishes make their first appearance.

These considerations lead to the question whether the dog-fish is sensi-

² From daily observations made by Mr. W. I. Denyse at the New York Aquarium.

tive to reductions in the density of the sea-water. Sheldon ('09) has contributed ample evidence of the great sensitiveness of various parts of the surface of its body to different chemical stimuli. The following instance is cited merely for the purpose of indicating an interesting problem for further investigation. At the New York Aquarium a tank about 250 cm. long, 35 cm. wide and 10 cm. deep was filled with harbor water. A very small *Squalus acanthias* about 35 cm. long, taken from harbor water, was placed in this tank. The brackish water continued to flow in at one end, while at the other end a stream of fresh water was run in. In a very short time the dog-fish turned about and swam to the end receiving the brackish water. It was then placed in the fresh water end, but swam again into the brackish water. After a number of trials, it was clear that the dog-fish was sensitive to the fresh water, as it persisted in seeking the saltier end of the tank. The nasal pouches were then packed with absorbent cotton and vaseline. The fish was again placed at various places in the tank, but swam about indifferently or remained stationary. Further investigation of this problem was not possible on account of the lack of proper facilities for experimenting with larger fishes.

The greater number of species of fishes on exhibition at the New York Aquarium are kept in the harbor water. What is the effect of such brackish water on the osmotic pressure of the blood of the elasmobranchs surviving it? Through the kindness of Dr. Townsend, the director, I was furnished with a number of dog-fishes, *Squalus acanthias*, for the purpose of securing an answer to the above question. At the time, the average specific gravity of the water was 1.015, which would correspond to a Δ of about 1.00°. The freezing point of the blood of seven fishes was as follows:

TABLE XII.—Freezing point of the blood of *Squalus acanthias* from New York harbor water

No.	Sex	Length in cm.	Δ of blood
1	♂	56	1.70 °
2		58	1.695
3		38	1.70
4		43	1.685
5		41	1.695
6		61	1.69
7		61	1.66

The average Δ of the seven fishes was 1.69°. This value is 0.18°

full strength sea-water, i. e., having a Δ of 1.82° . These dog-fishes are brought to the Aquarium from the fishing grounds near Sandy Hook. The Δ of the blood of two specimens from Vineyard Sound, Mass., was as follows:

a—female 56 cm. long, $\Delta = 1.81^\circ$.
 b— " 49 " " " $= 1.87^\circ$. Average $= 1.84^\circ$.

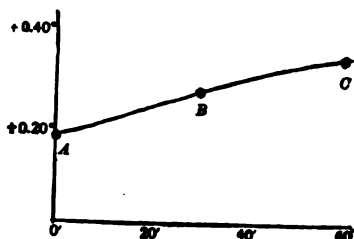
This is not far removed from that of *Mustelus*, which is 1.87° . A larger number of determinations would probably average 1.87° .

Evidently the normal osmotic pressure of the blood of *Squalus* undergoes a reduction, when the fishes are kept in the harbor water. It is also of interest to see that the blood does not become isotonic with the brackish water in which the fishes are kept. There appears to be a new equilibrium. If we assume that the blood of *Squalus* has normally the same mean Δ as that of *Mustelus*, then we can conclude that the Δ of the blood of *Squalus* has risen 0.18° , due to the immersion in brackish water. Moreover this is the value to be expected, if the change in the osmotic pressure of the blood bears a definite relation to the change in the osmotic pressure of the surrounding medium. The following proportion shows this: $1.795^\circ : 0.82^\circ :: 0.41^\circ : X$, in which 1.795° equals the difference between the Δ 's of sea-water and fresh water, 0.82° equals the difference between the Δ 's of sea-water and harbor water and 0.41° equals the maximum change in the freezing point of *Mustelus* after immersion in fresh water. X , on the basis of the above theory, should equal the Δ of the blood of the fish after immersion in harbor water. But X equals 0.187° , whereas 0.18° was the observed change in Δ . It seems to me that the chief point of interest, however, is that the organism maintains an osmotic pressure of its blood greater than that of the water in which it is kept. From what is known of the marine invertebrates, this property of the dog-fish is a distinct advance. Many of the dog-fishes brought into the Aquarium do not survive. It is interesting to speculate as to why any survive. Is it because the limiting membranes of the body are more resistant, or do these membranes become more resistant in response to the change produced in the osmotic pressure of their blood? On immersion in fresh water, *Squalis* did not show as great a reduction in the freezing point of its blood as was the case with *Mustelus*. This is shown by the following table, XIII:

TABLE XIII.—Change in Δ of blood of *Squalus acanthias* after immersion in fresh water for one hour

No.	Length in cm.	Rise in Δ after 30 minutes in fresh water	Rise in Δ after 60 minutes in fresh water
1	56	+0.090°	+0.110°
2	58	+0.085	+0.160
3	61	+0.130	+0.280
4	61	+0.090	+0.130

The average change during the first half hour is $+0.099^\circ$ and at the end of an hour amounts to $+0.165^\circ$. At the end of the same period in fresh water the blood of *Mustelus* had changed about 0.30° . At first it might be thought that the smaller change in the spiny dog-fish indicates an acquired immunity to the effects of dilute solutions of sea-water. It is possible that the limiting membranes of the body have become less permeable, thus preventing such a great change as in the blood of *Mustelus*, in the experiments with which the change in the external medium was greater. But, as was claimed above, the Δ of the blood of *Squalus* has risen 0.18° , due to the difference between the molecular concentration of sea-water and harbor water. Moreover the freezing point of its blood has risen an additional 0.16° , due to the transference of the fish from harbor water to fresh water. The total change is thus 0.34° , or nearly as great as that taking place in the blood of *Mustelus*, which was transferred directly from sea-water to fresh water. If this equality of modification in the osmotic pressure of the blood be true, then it follows that the limiting membranes of *Squalus* have acquired little or no resistance to the external medium; for their permeability has not changed. The change in the osmotic pressure of the blood is still proportional to the change in the osmotic pressure of the external medium. In Fig. 3, the point E, on line C—D, represents the Δ of the blood of *Squalus* from harbor water, which has a Δ of about 1.00° . Fig. 6 shows the changes in Δ of blood of *Squalus* due to immersion in fresh water. It will be noted that the in-

FIG. 6.—Changes in the Δ of blood of *Squalus* due to transference from harbor water to fresh water. A, in harbor water; B, 30 minutes in fresh; C, 60 minutes in fresh.

EFFECT OF LOSS OF BLOOD ON THE OSMOTIC PRESSURE OF THE BLOOD
OF *Mustelus canis*

In the previous experiments, it will be noted that varying quantities of blood were taken for the determination of the freezing point. About five cubic centimeters were used for each determination, and as much as six times that quantity was taken from many of the specimens. The criticism might be brought that the loss of so much blood might have introduced a serious modification in the results, so that what we were attributing to the difference between the molecular concentration of the blood and the surrounding medium might in large part be due to loss of blood. It was necessary therefore to make a control experiment in which the conditions should be the same as those described on page 13, with the exception that the fishes should be immersed in sea-water during the entire period.

Fano and Bottazzi ('96) observed changes in the osmotic pressure of the blood of dogs associated with anemia produced by successive bleedings. They noted that the osmotic pressure of the blood fell immediately after the bleeding. They explained this as being due to a temporary lowering of the blood pressure, which causes a diminution in the elimination of salts ordinarily released in secretions. As a result, those processes which are concerned in the formation of lymph are depressed. The authors suggested that the rise in the osmotic pressure may be due to the abundance with which globulins are turned into the blood stream. Globulins passing from the tissues into a less concentrated serum dissociate themselves and separate from the bases with which they are combined and contribute these to increasing the concentration of the blood.

The work of these investigators is hardly applicable here, for the reason that they experimented upon dogs. They took proportionately larger quantities of blood than were used in the experiments upon the dog-fishes. Moreover, days and weeks elapsed between the periods when the blood was tested.

In each of the following cases, after the spinal cord was destroyed, the fish was placed in a tank of sea-water. Then samples of blood were taken at intervals for the freezing point determination. Results were obtained from nine fishes which ranged in length from 56 cm. to 124 cm. and in weight from 538 gm. to 6482 gm. For each freezing point determination, about five cubic centimeters of blood were taken from the smaller fishes and ten cubic centimeters from the larger. The entire amount of blood in mammals is stated to be one-thirteenth of the body weight. It is also known that a loss of one-half of this amount does not

TABLE XIV.—Freezing point of the blood of *Mustelus canis* immersed in sea water

No.	Sex	Length in cm.	Weight in grams	Time	Δ	Change in Δ	Estimated percentage of blood used
1	♂	58	538	3.50 P. M.	1.82 °	0.000 °	40
				4.30 "	1.82	0.00	
				5.20 "	1.80	+0.02	
2	♀	56	538	11.40 A. M.	1.87	0.000	55
				2.00 P. M.	1.84	+0.03	
				3.20 "	1.82	+0.05	
				4.55 "	1.84	+0.03	
3	♂	62	624	3.00 P. M.	1.835	0.000	50
					1.845	—0.01	
					1.835	0.00	
					1.840	—0.005	
4	♂	71	936	2.30 P. M.	1.84	0.000	32
				3.30 "	1.86	—0.02	
				5.55 "	1.84	0.00	
				6.25 "	1.88	—0.04	
5	♀	79	1474	11.10 A. M.	1.93	0.000	54
				11.50 "	1.93	0.00	
				2.30 "	1.91	+0.02	
				3.15 "	1.89	+0.04	
				4.30 "	1.88	+0.05	
6	♂	79	1588	3.20 P. M.	1.86	0.000	51
				4.00 "	1.90	—0.04	
				4.40 "	1.90	—0.04	
				5.20 "	1.90	—0.04	
				5.50 "	1.90	—0.04	
7	♀	84	1474	9.55 A. M.	1.81	0.000	67
				10.25 "	1.83	—0.02	
				10.55 "	1.83	—0.02	
				11.25 "	1.86	—0.05	
				12.00 M.	1.85	—0.04	
				3.00 P. M.	1.86	—0.05	
8	♀	112	4366	9.35 A. M.	1.81	0.000	18
				10.10 "	1.84	—0.03	
				11.00 "	1.85	—0.04	
				1.30 P. M.	1.86	—0.05	
				5.00 "	1.86	—0.05	
9	♀	124	649½	3.00 P. M.	1.84	0.000	28
				3.30 "	1.89	—0.05	
				4.00 "	1.90	—0.06	
				4.30 "	1.92	—0.08	
				5.00 "	1.92	—0.08	
				5.30 "	1.93	—0.09	
				7.00 "	1.92	—0.08	
				7.35 "	1.92	—0.08	
				8.00 "	1.92	—0.08	
				8.30 "	1.93	—0.09	

prove fatal. Hyde ('08) estimated that the blood of the skate is equal to one-twentieth of its body weight. Even if we assume that the total quantity of blood of *Mustelus* is equal to five per cent of its body weight, in none of the preceding experiments was one-half of the total blood of the body taken. Table XIV shows the results of the experiments in which the Δ 's of the blood were obtained from different samples taken at intervals from the caudal artery of fishes immersed in sea-water.

In the above series of experiments, more blood was intentionally taken for each determination of Δ than was used in the preceding cases. As indicated above, the object of the experiments was to ascertain the effect of bleeding on the osmotic pressure of the blood. There was no difficulty in obtaining blood from any of the fishes experimented upon in the present connection. All were alive and breathing regularly at the time the last sample was obtained. The percentage of the total quantity of the blood given in each case is only a rough estimate based on the assumption that the total quantity equals five per cent of the body weight. In estimating this, the last sample was not included. In reviewing the results, it is to be noted that there is a slight rise in the freezing point of the blood of specimens 1, 2 and 5. The remaining six show a fall in the freezing point. On referring to the accompanying data in each case, it is found that the rise or fall in Δ is not related to the sex, length or weight of the fishes, or to the amount of blood taken. In many of the cases after the initial change, there is no further modification in Δ . It is possible that these small variations from the normal Δ are indications of the normal fluctuations in the osmotic pressure as maintained on page 6. The evidence presented in Table XIV is offered as further support for this conclusion. Finally, attention is called to the fact that the maximum changes are slight as compared with those recorded as due to the effects of fresh water and concentrated sea-water. On the whole we are justified in concluding that the effects recorded in Tables VII and VIII were due to the modifications in the molecular concentration of the external medium. Buglia ('08) found that simple bleeding produced in the physico-chemical properties of dog's blood variations absolutely negligible as compared with those obtained after injections of salt solutions hyper-tonic to the blood.

ADDITIONAL CHANGES IN THE BLOOD DUE TO ALTERATIONS IN THE CONCENTRATION OF THE EXTERNAL MEDIUM

CHANGES IN THE ERYTHROCYTES

One might conclude from the above changes in the osmotic pressure of the blood of fishes exposed to fresh water that the corpuscles were laked

by the dilution due to the entrance of water into the blood and that this might be a contributing cause of death. In fact, Mosso ('90) working at Naples made this the basis of his explanation of the death of elasmobranchs under this condition. The freezing point of the sea-water from the Mediterranean is about 26 per cent lower than that of the water at Woods Hole. The degree of change to which the fishes were subjected when placed in fresh water was therefore greater in the case of the fishes with which Mosso worked. This difference may account in part for the divergence of my results from those of Mosso. Mosso stated that, if the tail of *Scyllium* was cut off after the fish had been in fresh water for half an hour, no more blood flowed from the artery, while the heart still continued to beat. On the other hand, I found that blood might be obtained from the caudal artery of *Mustelus* up to the point of death in fresh water, i. e., from one to two hours. Mosso also claimed that the serum remained almost normal at the time of death in fresh water. We have here noted a profound lowering of the osmotic pressure of the serum. The results obtained by Garrey ('05), Dakin ('08) and myself show that this statement of Mosso's cannot be correct. Mosso believed the real cause of death to be due to suffocation. By the action of the fresh water, the red blood cells go to pieces and clog up the capillaries of the gills, thereby cutting off the exchange of gases in these structures.

Following up this hypothesis, Mosso studied the osmotic resistance which the red cells offered to different salt solutions. For example, the erythrocytes of selachian blood were destroyed in 2.5 per cent solutions of sodium chloride and the fluid soon became red. Teleosts like *Conger* and *Muræna* had a greater resistance and first lost their hæmoglobin in a 0.3 per cent NaCl solution. Mosso found that fresh water forms possessed blood more resistant to salt solutions of different dilution than marine teleosts, while anadromous fishes like *Anguilla* and *Acipenser* possess blood cells which are especially resistant to dilute salt solutions.

On account of the divergence between my observations and those of Mosso, I concluded to ascertain whether at the time of death as the result of immersion of *Mustelus* in fresh water its corpuscles were laked. This was ascertained in the following way: The spinal cord of a dog-fish taken from sea-water was destroyed. About ten cubic centimeters of blood were drawn from the caudal artery. This was closed, and the fish was transferred to sea-water which was rapidly changed to fresh. Near the time of death, the artery was opened a second time and a second sample of blood was obtained. Soon after each sample of blood was taken, it was defibrinated. Then each was placed in a separate centrifuge tube and the two were simultaneously centrifuged. At the end of this process, the

serum of the normal blood was perfectly clear, while that of the other showed in some cases faint traces of laking. In other cases it was difficult to detect any such indication. On the whole, it was thus demonstrated that there was no marked laking of the corpuscles after immersion of the fish in fresh water.

In Fig. 7, N represents the osmotic pressure of the blood of *Mustelus*, in sea-water; F represents the osmotic pressure of the blood at the time of death in fresh water; while S represents the osmotic pressure of the first solution of NaCl in which the blood is laked. In solutions more concentrated than this the blood is not laked.

I made camera lucida drawings of the corpuscles from both fishes and observed no measurable differences in size. These corpuscles are oval and



FIG. 7.—Diagram showing comparative Δ 's of blood of *Mustelus* in sea-water, N; in fresh water, F; and of saline solution, S, in which blood is first laked.



FIG. 8.—Showing the difference between the ratios of volume of corpuscles to plasma in normal blood, N, as compared with blood taken from fishes after immersion in fresh water, H.

flat, so that, in preparations made of them, the flat surface only would be observed and there would appear no indication of their thickness. It then occurred to me to make hæmatocrit studies of the blood under normal and experimental conditions. The following results were obtained. The ratio of the volume of corpuscles to that of serum of normal blood was found to be about 23 to 77, i. e., the corpuscles form less than 25 per cent of the total volume of defibrinated blood. Blood from the same specimen near death after immersion in fresh water showed a ratio of 31 to 69, that is,

was as 20.5 to 79.5. After immersion in fresh water the ratio was 30.77 to 69.23. Fig. 8 shows this difference. In this figure, N represents the ratio between the volume of corpuscles and serum in normal blood. H represents the ratio from blood taken from fishes after immersion in fresh water. Shaded portions represent corpuscles. Considering these results in connection with those obtained by the use of the camera lucida, we may conclude that at least some of the corpuscles are swollen after immersion of the fish in fresh water. The faint trace of laking at the end of the experiment indicates that at least some of these swollen corpuscles cannot withstand the increased pressure of distension by the absorption of water. These burst and cause the faint trace of laking noted above. In fact, in preparations made of the corpuscles of a fish that had died in fresh water, some corpuscles were found broken down.

Since Mosso claimed that the resistance of the erythrocytes of fishes varied in a general way with the salt content of the blood, I determined to ascertain the strength of solutions of NaCl which would cause the laking of the blood of elasmobranchs common at Woods Hole. He found that the erythrocytes of selachians at Naples were laked by solutions more dilute than 2.5 per cent NaCl. The sea-water from the Mediterranean is isotonic with a 3.8 per cent sodium chloride solution. A 2.5 per cent sodium chloride solution is about 34 per cent more dilute than the water from the Mediterranean. A reduction of 34 per cent in the salinity of the sea-water from Woods Hole would give a solution isotonic with 1.2 per cent solution of NaCl. So that according to Mosso's hypothesis the blood of the Woods Hole elasmobranchs should be laked in a 1.2 per cent solution of NaCl and in all solutions more dilute than this. I made up ten solutions of NaCl. The first was a 2 per cent solution, the second a 1.8 per cent solution, the remaining solutions decreased respectively 0.2 per cent, the last being a .2 per cent solution. I tried the effect of these solutions on the defibrinated blood of the smooth dog-fish, *Mustelus canis*, the spiny dog-fish, *Squalus acanthias*, the sand shark, *Carcharias litoralis*, and the skate, *Raia erinacea*. Following are the results of the experiments:

Experiment 1. *Squalus acanthias*. Male. 29 inches long.

No laking in 2 per cent NaCl to 1.0 per cent NaCl. Faint trace in 0.8 per cent NaCl. Decided in 0.6 per cent NaCl.

Male. 19+ inches long.

Experiment 3. *Carcharias littoralis*. Female. 48 inches long.

No laking in 2.0 per cent NaCl to 1.2 per cent NaCl. Faint trace in 1.0 per cent NaCl. Decided in 0.8 per cent NaCl.

Experiment 4. *Raia erinacea*. Female. 20 inches long.

No laking in 2.0 per cent NaCl to 1.2 per cent NaCl. Faint trace in 1.0 per cent NaCl. Decided in 0.8 per cent NaCl.

It is clear that Mosso's statement is not applicable to the elasmobranchs from the Woods Hole region. In the case of the four species here indicated, there is no laking down to the 1.0 per cent NaCl solution and even this dilution does not decidedly lake the blood. Bottazzi ('06) found that the blood of elasmobranchs at Naples was more resistant than Mosso claimed; the first solution to lake the corpuscles was approximately a 2.0 per cent to 1.75 per cent solution of NaCl. Rodier ('99) found that elasmobranchs at Arcachon lost the hæmoglobin of their corpuscles in less dilute solutions than Mosso found to be the case with the elasmobranchs at Naples. Bottazzi ('06) explained this difference as being due to the difference in the salinity of the water at the two places. Thus the Δ of the sea-water at Naples is 2.29° , while the Δ of the sea-water at Arcachon is 2.00° . The average concentration of the laking solutions at Arcachon was 1.46 per cent NaCl. It appears that the corpuscles of the elasmobranchs at Woods Hole are much more resistant than those at Naples or at Arcachon, and more resistant than can be accounted for by the difference in the salinity of waters. Rodier ('99) believed that the urea in elasmobranch blood had something to do with the difference in the hæmolytic relations of elasmobranch and teleost blood; but Bottazzi ('99) found that even in a 6 per cent solution of urea which is almost isotonic with the blood the corpuscles lost their hæmoglobin. He came to the conclusion that in addition to the osmotic pressure exerted by the substances dissolved in the blood each of these substances and especially the sodium chloride exerted a specific chemical effect upon the corpuscles, thus maintaining their integrity. I made up a second series of solutions containing the same percentage of sodium chloride as the preceding series, but in addition each solution contained as much urea as NaCl, for the reason that elasmobranch blood contains about the same amount of urea as salts. In each case the corpuscles appeared at first sight to be more resistant in the solution of NaCl and urea than in the NaCl solutions. This is as follows:

Mustelus canis—Corpuscles laked in 0.8 per cent NaCl and 0.6 per cent NaCl + urea.

Squalus acanthias—Corpuscles laked in 0.6 per cent NaCl and 0.4 per cent NaCl + urea.

Carcharias—Corpuscles laked in 0.8 per cent NaCl and 0.6 per cent NaCl + urea.

It is of interest to note that the Δ of the 0.8 per cent NaCl solution is 0.50° , while that of the 0.6 per cent NaCl + urea solution is 0.56° ; that is, the molecular concentrations of the two are quite similar. The Δ of the 0.6 per cent NaCl solution is 0.39° and that of the 0.4 per cent NaCl + urea solution is 0.38° . In other words, the osmotic pressures of the two solutions which first cause laking are in each case similar. The urea in the second set of solutions merely raises the osmotic pressure to the osmotic pressures of the solutions of NaCl. It must be concluded that, since the urea takes the place of the NaCl in these dilute solutions, at least neither the NaCl nor the urea exerts any specific chemical effect upon the corpuscles. The fact that such a great reduction in the osmotic pressure of the external medium is necessary before the hæmolysis of elasmobranch blood shows that the integrity of the corpuscle does not depend upon the equality of osmotic pressures between corpuscle and plasma. The corpuscles maintain their integrity even though there is a fall of over 40 per cent in the osmotic pressure of the surrounding medium. We have seen above that Mosso concluded that the resistance of the erythrocytes of the blood varied in a general way with the salt content of the blood. Since the blood of marine teleosts contains very much less salt than that of elasmobranchs, we should expect that teleost corpuscles would be much more resistant than those of elasmobranchs. Mosso found this to be true of the teleosts studied by him. My results differ in some respects from those of Mosso. The teleosts studied by me show but a small increase in the resistance of their corpuscles over that of the elasmobranchs which I examined. This is shown by the following results:

Experiment 5. Weakfish, *Cynoscion regalis*. Female. 30 inches long.

No laking in 2.0 per cent NaCl to 0.8 per cent NaCl. Laking decided in 0.6 per cent NaCl.

Female. 20 inches long.

Same results as above.

Experiment 6. Scup, *Stenotomus chrysops*. 8 inches long.

No laking in 2.0 per cent NaCl to 0.8 per cent NaCl. Distinct in 0.6 per cent NaCl. Decided in 0.4 per cent NaCl.

Experiment 7. Killifish, *Fundulus heteroclitus*. About twenty specimens used.

No laking in 2.0 per cent NaCl to 0.8 per cent NaCl. Laked in 0.6 per cent NaCl.

Experiment 8. Flounder, *Pleuronectes*. Female. 15 inches long.

No laking in 2.0 per cent to 0.8 per cent NaCl. Faint in 0.6 per cent NaCl. Distinct in 0.4 per cent NaCl.

Experiment 9. Mackerel, *Scomber scombrus*. 10 inches long.

No laking in 2.0 per cent to 0.8 per cent NaCl. Distinct in 0.6 per cent NaCl. Decided in 0.4 per cent NaCl.

Experiment 10. Butterfish.

No laking in 2.0 per cent NaCl to 0.8 per cent NaCl. Laked in 0.6 per cent NaCl.

According to Rodier and Quinton the blood of marine teleosts contains about 0.6 per cent salts, while that of elasmobranchs has about 1.7 per cent. I have found that the blood serum of *Mustelus* contains .86 per cent Cl, while that of the blood of the flounder, *Pleuronectes*, a marine teleost, has .53 per cent Cl. The equivalent in NaCl for the dog-fish is 1.42 per cent, while for the flounder it is 0.87 per cent; and yet we have

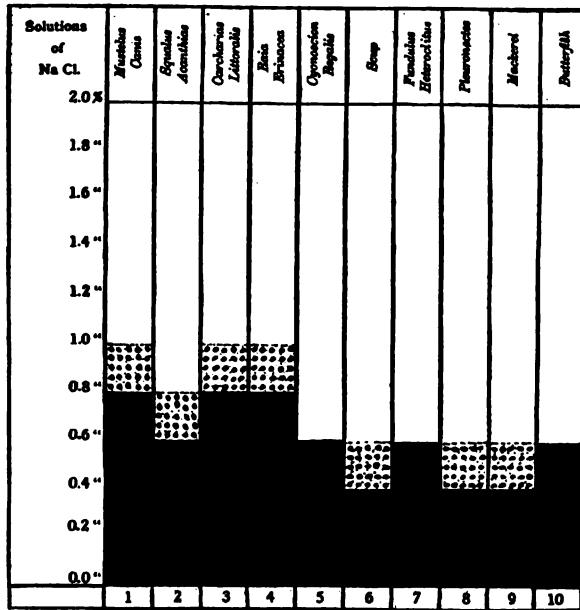


FIG. 9.—Showing the hemolytic effect of different NaCl solutions on the erythrocytes of four species of elasmobranchs and six species of teleosts. Nos. 1-4 = elasmobranchs; 5-10 = teleosts. Blank spaces, no laking; dotted spaces, faint laking; dark spaces, decided laking.

found that in the spiny dog-fish the first decided laking occurred in the 0.6 per cent solution of NaCl; in the other three elasmobranchs, in the 0.8 per cent NaCl solutions. In three marine teleosts studied the first decided laking occurred in the 0.6 per cent solutions, while in the other three species decided laking first occurred in the 0.4 per cent NaCl solution. Fig. 9 shows the hæmolytic effect of different NaCl solutions on the

corpuscles of four elasmobranchs and six teleosts. Although on the whole, teleost corpuscles are laked by a more dilute solution than is the case with elasmobranch corpuscles, the difference is small as compared with that given by Mosso. The degree of dilution of the solution which first lakes the corpuscles in the two cases is not proportional to the degree of departure from the normal salinity of the blood. Bottazzi and Ducceschi ('96) pointed out that no parallel relation exists between the resistance of the corpuscles and the osmotic pressure of the serum of animals from the different vertebrate phyla. So we may conclude from the above results that whatever be the function of the osmotic pressure of the serum, this is not primarily for the purpose of maintaining the integrity of the corpuscle so far as the retention of its hæmoglobin is concerned. We have seen that the hæmoglobin is retained even though profound changes in the osmotic pressure of the serum take place. Relatively speaking, elasmobranch corpuscles have a greater range in the resistance of their corpuscles than is the case with regard to marine teleosts. They withstand a greater relative reduction of the osmotic pressure of the surrounding medium, *i. e.*, serum, before the hæmoglobin is lost, than is the case of the teleosts. That the death of *Mustelus* is not due to the laking of the blood is seen from the above facts. The swelling of the corpuscles, as shown by hæmatocrit and centrifuge measurement, is probably a matter of greater importance. The imbibition of water may interfere with the gaseous exchanges in the capillaries of the gills. The blood taken in the centrifuge and hæmatocrit measurements described here must have been changed in the gill capillaries and continued to circulate. The gill capillaries do not become completely clogged up with broken down corpuscles as Mosso claimed, as is shown by the fact that the blood used in all these experiments was taken from the caudal artery. The blood of *Mustelus* is first decidedly laked in a 0.8 per cent NaCl solution. The freezing point of such a solution is -0.50° ; but it has already been shown that the freezing point of the blood of *Mustelus* at the time of death in fresh water is about -1.45° , which indicates a dilution insufficient to cause laking. It may be, however, that the stream of blood flowing through the capillaries of the gills is met by an influx of water sufficient to lake some of the corpuscles as they pass by. The experiments demonstrate individual differences in corpuscles, since some are laked and some are not. Whether or not all of the corpuscles are swollen would be diffi-

CHANGES IN THE SPECIFIC GRAVITY OF THE BLOOD

The method of Hammerschlag was used in the determination of the specific gravity of the blood of *Mustelus* under normal and experimental conditions. After the normal specific gravity of the blood of each specimen was obtained, the fish was placed in fresh water until near death. Each value of specific gravity given below is the average of four or five determinations.

TABLE XV.—*Showing the specific gravity of the blood of Mustelus in sea-water and after immersion in fresh water*

A—Normal specific gravity of blood	B—Specific gravity of blood in fresh water
No. 1 = 1.0490	1.0483
No. 2 = 1.0448	1.0359
No. 3 = 1.0452	1.0410
Average = 1.0466	1.0417

A fall in the specific gravity of the blood is shown to have taken place after immersion of the fish in fresh water. The blood is therefore more dilute.

CHANGES IN THE PERCENTAGE COMPOSITION OF THE WATER AND THE SOLIDS OF THE BLOOD

It has been shown that profound changes in the molecular concentration of the blood take place when *Mustelus* is immersed in fresh water and concentrated solutions of sea-water. To what are these changes due? Fredericq ('04) concluded that they were caused by absorption of water into the blood. Centrifuge measurements of the blood of *Scyllium* modified by immersion of the animal in diluted sea-water, appeared to show an increase in the relative quantity of plasma. Dakin ('08) held the same view, for he claimed that the modifications in the osmotic pressure of the blood which took place when *Acanthias* had been immersed in fresh water were due to the blood gaining water, and that equilibrium between the internal and the external medium was established by the gain or loss in water being counterbalanced by absorption followed by secretion from the kidneys.

If the modifications in the osmotic pressure of the blood be due merely to the addition or subtraction of water from the gills, then the gills are

semi-permeable structures. From what is known of other animals, it is safe to infer that a reasonable excess of water in the blood would be eliminated by the excretory organs. On the other hand, it has already been shown that at the time of death the freezing point of the blood has risen 21.9 per cent. If the blood be merely diluted, the decrease in solids, organic and inorganic, should be proportional to the increase in water. None of the previous investigations contain references to the percentage of water in the blood under the experimental conditions here described. I obtained data with regard to this matter as follows: A certain quantity of blood was drawn from the caudal artery of a dog-fish taken from seawater. After the artery was closed, the specimen was placed in fresh water for about one hour. The fish was then removed and a second sample of blood was obtained. Both samples were weighed, placed in a hot-air bath at a temperature of about 100° C. and dried to constant weight. The percentage of the dried material was then computed and from this value the percentage of water was obtained. The results are shown in Table XVI.

TABLE XVI.—Percentage of water and solids of the blood of *Mustelus* in seawater and after immersion in fresh water

A—Normal blood		B—Hypotonic blood	
Water	Solids	Water	Solids
85.39%	14.61%	88.28%	11.72%
87.04	12.96	89.80	10.20
87.06	12.94	88.94	11.06
86.76	13.24	88.81	11.19
89.08	10.92	89.69	10.31
84.38	15.62	87.09	12.91
82.36	17.64	87.23	12.77
82.69	17.31	85.46	14.54
87.60	12.40	88.49	11.51
86.65	13.35	87.36	12.64
87.69	12.31	88.83	11.17
88.18	11.82	89.26	10.74
89.41	10.59	91.01	8.99
Average=86.48%	13.52%	88.48%	11.52%

The average percentage of water in normal blood is found to be 86.48, while that of the blood of the same specimens after immersion in fresh water is 88.48, a gain of 2.0 per cent. Is this gain in water sufficient to account for a rise in the freezing point of the blood of 0.40°? I have

rise of the freezing point equal to that produced in the dog-fishes after immersion in fresh water. It does not seem that in immersion sufficient water has been added to the blood to cause the above lowering of the freezing point. It may, however, be objected that the calculation of the percentage of water in the two cases does not present the matter in its true light. Any addition of water to the blood will separate the cells in the blood to the same degree that it dilutes the soluble substances in the blood. The determination of the dry weight of the blood, therefore, would give a more nearly correct idea of the degree to which the solid substances of the blood are diluted. Normal blood contains 135.2 parts of dried material p. m., while the blood from fishes immersed in fresh water contains 115.2 parts of dried material p. m. That is, the blood after immersion of the animal in fresh water contains 14.8 per cent less dried material than the normal blood. This means first of all less corpuscles; but it also means 14.8 per cent less organic and inorganic substances. It is the inorganic substances in solution which determine in great part the osmotic pressure of the blood. From this standpoint, then, the dilution of the blood has caused a reduction of 14.8 per cent in the osmotic pressure of the blood; but such a dilution is insufficient to account for the rise of the freezing point of the blood actually observed, *i. e.*, 21.9 per cent. It must be concluded, then, that this is not altogether due to mere dilution of the blood by the absorption of water.

CHANGES IN THE NITROGEN CONTENT OF THE BLOOD

A comparison between the organic solids of normal blood and those of the blood after the immersion of the fish in fresh water would also be an index of the dilution of the blood; but the amount of nitrogen present is indicative of the amount of organic material, and therefore I concluded to make determinations of the nitrogen. I wish to thank Dr. W. Denis of the Laboratory of Biological Chemistry of the Harvard Medical School for suggestions as to a modification of the Folin micro-chemical method for the determination of urea which I used in making the nitrogen determinations. After a sample of normal blood was taken, the fish was placed in fresh water until near death. A second sample was then drawn from the caudal artery. Table XVII shows the results of the analysis.

TABLE XVII.—Nitrogen content of the blood of dog-fishes in sea-water and after immersion in fresh water

No.	Length in cm.	Weight in gm.	A—Nitrogen in normal blood. Mg. in 1 c. c.	B—Nitrogen in blood after immersion in fresh water. Mg. in 1 c. c.
1.....	72	1077	22.697	18.125
2.....	74	1191	22.775	19.145
3.....	69	1049	23.150	19.875
4.....	74	1389	23.812	20.825
Average.....			23.109	19.493

The average quantity of nitrogen in the normal blood of *Mustelus* is 23.109 mg. per c. c., while after the immersion of the fish in fresh water it has fallen to 19.493 mg. This means that by immersion the blood has lost 15.6 per cent of its nitrogenous matter. Hæmoglobin is a large nitrogenous component of the blood. It has already been shown that the blood is not laked by the changes produced in its osmotic pressure by the fresh water. The hæmoglobin therefore cannot have left the blood. The greater part of the remaining nitrogenous matter in the blood is present in the proteins of the plasma. It is improbable that they diffuse out through the gills.

On the whole, the conclusion must be drawn that the dilution due to the addition of water to the blood will account for a loss of but 15.6 per cent in the substances in the blood, and also a rise in the freezing point of but 15.6 per cent.

CHANGES IN THE UREA CONTENT OF THE BLOOD

It has been known for some time that urea is present in unusually large quantities in selachian blood. Thus von Schröder ('90) found that the blood of *Scyllium* contained 2.6 per cent urea, and this was afterward confirmed by other investigators. Urea is usually regarded as a readily diffusible substance. Its gram-molecular solution has about the same osmotic pressure as sea-water, i. e., 22.4 atmospheres. When *Mustelus* is immersed in fresh water, will the urea with its high osmotic pressure diffuse through the extremely thin membranes of the gills and the capillary blood vessels into the fresh water, with a Δ of but 0.025°? Dr. Denis has kindly made for me the following determinations of the urea in blood

TABLE XVIII.—Urea content of the blood of *Mustelus canis* in sea-water and after immersion in fresh water for one hour (see Table X for sex, length, and weight)

	Urea in normal blood, grams p. m.	Urea in blood after immersion, grams p. m. in fresh water
Fish No. 1.....	15.4	12.6
" " 2.....	15.8	13.2
" " 3.....	15.0	13.2
" " 4.....	15.6	13.2
Average.....	15.45	13.05

This means that the blood lost 15.5 per cent of its urea after immersion in fresh water. The normal blood of *Mustelus* contains 1.55 per cent of urea. This has a freezing point of about -0.45° , and 15.5 per cent of this equals 7.3° . The change in the molecular concentration of the blood is therefore due to other causes than a diminution in the urea. Moreover, the diminution in the urea content is approximately the same as that of the total nitrogen and solids, which, as has been said, indicates in all probability the changes produced by dilution of the blood due to the absorption of water through the gills. These results also show that the maximum change in the osmotic pressure of the blood is due to causes other than its mere dilution.

CHANGES IN THE SALT CONTENT OF THE BLOOD

It has been concluded that sufficient water has not been absorbed to account for the lowering of the osmotic pressure of the blood which my experiments demonstrate to have taken place, when *Mustelus* is immersed in fresh water. Baglioni ('05) and others have shown that the blood of the elasmobranchs that they studied contains about 2 per cent of salts and 2.6 per cent of urea. Although both of these substances contribute to the osmotic pressure of the blood and are readily diffusible, it is generally held that neither diffuses into the external medium when the fish is immersed in fresh water. Yet it has been shown in the preceding experiment that a decrease of 15 per cent in the solids of the blood takes place. Are the salts decreased to a like amount?

In a first series of experiments the blood was weighed, dried to constant weight and ashed, and the ash was analyzed for chlorine by the Volhard method. I wish to thank Dr. George F. White of Clark College and Mr. W. J. Crozier of the College of the City of New York for valuable advice

and assistance in the chemical technique here involved. The chlorine in the blood is an index of the salts present. As a check on the method the chlorine content of successive samples of blood from five fishes taken from sea-water was determined. For purposes of comparison the quantity of chlorine present is expressed in grams per 1000 grams of blood. The average amount of chlorine in the first sample of blood taken from each of the five specimens was 6.597 grms. p. m. The average amount of chlorine in the second sample was 6.668 grms. p. m. The difference is within the limits of experimental error. The analysis corroborates the results obtained by measuring the freezing points of successive samples of the blood of the dog-fish taken from sea-water. In a second series of experiments, after a normal sample of blood had been taken from each of five fishes, the fishes were placed in a concentrated solution of sea-water having a Δ of about 3.15° for one hour, at the end of which a second sample of blood was drawn from each specimen. The average amount of chlorine from the normal blood amounted to 6.249 grams per 1000 grams of blood. The average amount of chlorine in the blood after the immersion of the fishes in the concentrated sea-water was 7.522 grams p. m. A gain of 20.4 per cent in chlorine is indicated, which under these conditions probably means a gain of 20.4 per cent in salts. In the third place, an analysis was made of the chlorine content of the normal blood of twenty specimens of *Mustelus canis*. In some cases the blood of two or even three specimens was mixed for a single analysis. Analyses were also made of the blood of twenty fishes after immersion in fresh water. The average quantity of chlorine in the normal blood was 6.098 grams p. m., while the average quantity of chlorine in the blood after immersion of the animal in fresh water for about one hour was 4.638 grams p. m. This means that the blood had lost 23.9 per cent in chlorine; but in this case also the loss in chlorine probably means an equivalent loss in salts. It has thus been shown that on immersion of the animal in a concentrated solution of sea-water the blood gains in chlorine; on immersion in fresh water the blood loses in chlorine.

In order to avoid possible errors due to the volatilization of chlorides through ashing, I decided to make an analysis of the serum of the dog-fish under the above described experimental conditions.

After the blood was drawn in each case, it was first defibrinated and then centrifuged. The supernatant serum was drawn off with a volumetric pipette. In some cases it was necessary to use the mixed sera of

were heated to boiling for about two minutes, after which the liquid was allowed to cool, the flask was filled to the mark with distilled water and the contents were shaken. The whole was then filtered and 50 c. c. of the filtrate was used for an analysis of its chlorine by the Volhard method. The amount of chlorine thus determined was multiplied by two, giving the amount present in the original 5 c. c. of serum, and from this the amount present in 1000 parts of serum was easily calculated. Table XIX shows the results of the analysis of the chloride in five samples of serum taken from seven fishes immersed in sea-water and in six samples of serum taken from six fishes that had been transferred from sea-water to fresh water for somewhat over an hour.

TABLE XIX.—*Chlorine content of the blood serum of dog-fishes in sea-water and after immersion in fresh water*

Number	Chlorine in serum from fishes taken from sea-water, in grams p. m.	Number	Chlorine in serum from fishes after immersion in fresh water, in grams p. m.
1.....	8.778	1.....	5.824
2.....	8.400	2.....	6.755
3.....	8.246	3.....	6.181
4.....	8.715	4.....	6.608
5.....	9.079	5.....	6.734
		6.....	6.433
Average....	8.643	Average....	6.422

The average in the case of the first group is 8.643 p. m., while that for the second group is 6.422 p. m., a difference of 25.7 per cent, representing the loss of chlorine resulting from the immersion.

The greater percentage of Cl in the serum than in the blood is due to the fact that practically all the chlorides of the blood are dissolved in the serum. The significant feature of the two groups of analyses is that the percentage loss in chlorine is approximately the same in the two cases. The results warrant the conclusion that after immersion in fresh water for about an hour, *i. e.*, until near death, the blood contains about 25 per cent less chlorine in solution than is the case with normal blood. This means that the salt content of the blood is less than the urea and other nitrogenous substances. If there had been no loss of salts by diffusion, then there should have been a decrease of but 15 per cent in the salts at the end of the period of immersion in fresh water. We are driven logically to the conclusion that the excessive diminution in the salts of the

blood takes place by diffusion through the gills and that the gill membranes become permeable to them.

REGULATION OF THE OSMOTIC PRESSURE OF THE BLOOD OF *MUSTELUS*

A constant osmotic pressure of the blood is regarded as necessary for the normal activities of cells and tissues of the higher forms. The kidneys are recognized as being primarily concerned in maintaining this constant pressure. Their activity in this connection will be considered later. In addition to the kidneys, it has been pointed out by Buglia ('09) that the tissues take part in this regulation. Buglia found that injections of hypotonic salt solutions into the circulation of a dog produced little effect on the molecular concentration of the blood. He concluded that the excessive water disappeared with astonishing rapidity from the blood plasma by entering the cells or tissues. In this way the normal osmotic pressure of the blood was maintained. Japelli ('06) found after intravenous injections of hypotonic solutions of sodium chloride into the circulation of the dog, that the muscles took up water from the blood, thus exerting a regulative action on the osmotic pressure of the blood. When *Mustelus* is immersed in fresh water, its tissues are bathed by diluted blood. Is there any evidence of an attempt on the part of the tissues to maintain the normal osmotic pressure of the blood by taking up water from the hypotonic blood which bathes them? Various organs, namely, the brain, heart, kidney, spleen and muscle, were removed from several dog-fishes which had been in sea-water. The same organs were removed from other fishes that had been immersed in fresh water until near death. Each organ was placed on filter paper, the heart and brain being cut open, and the other organs being cut into small pieces. All free fluids were removed with filter paper. Each organ was then weighed and put at first into a hot-air bath at 100° C. for a time and then into a dessicator over sulphuric acid. A partial vacuum was made by withdrawing air by means of a filter pump. When the organs were dried to constant weight, the percentage of water in each case was calculated. The results of this experiment are shown in Table XX.

TABLE XX.—Percentage of water in various organs of the dog-fish when the animals were taken from sea-water and after they had been immersed in fresh water for about two hours

Brain		Heart		Kidney		Spleen		Muscle	
Norm.	Hypo.	Norm.	Hypo.	Norm.	Hypo.	Norm.	Hypo.	Norm.	Hypo.
<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>
79.2	81.8	81.2	83.6	76.6	82.1	76.4	81.0	74.4	81.5
82.9	82.8	84.2	85.3	81.5	82.6	77.2	81.6	80.4	77.8
81.9	83.0	81.0	84.7	77.9	81.6	77.9	77.9	78.7	78.9
77.0	82.0	80.0	86.0	79.8	82.0	79.4	77.8	77.6	83.0
78.9	83.3	80.6	86.8	97.3	79.6	78.6	82.2	77.5	83.9
81.7	87.6	80.6	85.7	78.3	84.0	78.3	84.1	79.7	82.5
79.1	87.6	79.3	87.4	79.6	86.4	78.1	84.3	80.8	84.7
82.3	86.4	80.2	86.2	79.5	86.2	77.6	81.9	79.2	85.1
80.2	88.2	81.0	97.0	78.9	87.4	77.6	80.6	79.1	77.6
79.0	88.3	81.7	89.1	79.7	85.4	76.7	80.6	78.2	82.7
78.7	81.5	80.6	81.7	78.8	80.8	78.5	71.9	77.2	80.2
79.7	80.8	82.0	82.1	78.1	80.8	78.2	78.7	81.6	80.5
77.9	82.1	80.6	81.3	78.3	79.7	78.6	78.6	78.7	82.9
79.7	82.3	80.3	82.6	78.2	82.8	77.1	75.6	85.5	82.0
78.3	81.6	81.1	83.5	82.1	81.5	78.3	80.7	78.9	85.3
75.6	81.5	78.9	83.5	78.3	80.7	77.0	80.5	80.2	80.5
	81.5	80.3	84.2	78.5	81.3	78.5	80.1	83.5	79.1
	81.3	82.6	81.6	79.1	80.4	77.3	79.4	77.8	....
	....	74.3	83.7	75.3	82.1	....	79.2	....	....
Averages, 79.5	83.6	80.5	84.5	79.3	82.5	77.8	79.8	79.4	81.7

An examination of the table shows that the organs of the animals that had been immersed in fresh water contain more water than those of normal animals; the various tissues show the following increases: Brain, 4.1 per cent; heart, 4.0 per cent; kidney, 3.2 per cent; spleen, 2.0 per cent; muscle, 2.3 per cent. The average percentage of water in normal tissues was 79.3 per cent, while in the fresh water specimens it was 82.4 per cent, an average gain of 3.1 per cent. It thus seems certain that the tissues take up a certain amount of water from the blood, when this is made hypotonic by the immersion of the fish in fresh water. From this it must be concluded that the tissues of an animal constitute a mechanism for the regulation of the osmotic pressure of the blood.

It was stated above (p. 51) that the kidneys are concerned in the regulation of the osmotic pressure of the blood of higher forms. Mammals after drinking a great amount of water secrete a greater amount of urine than usual. This urine is also more dilute than normal urine. Whereas in man urine usually has a specific gravity of 1.020, the dilute urine may have a specific gravity of 1.002 (Hammarsten). Overton found that water absorbed through the skin of the frog is excreted by the kidneys.

Fischer ('10) found that if a ligature was tied about a frog's leg and the animal was put into fresh water the leg became greatly swollen because of the absorption of water. The circulation of the blood and lymph being stopped by the ligature, the kidneys could not pass off the excess of water. Will the kidneys of *Mustelus* act in the presence of the diluted blood in such a manner as to conserve the normal osmotic pressure of the blood?

Observations were made by Dr. W. Denis and the author on the quantitative secretion of the urine of *Mustelus*. The method of collection has been described by Denis ('12). The average secretion of urine per 24-hour period was 21.6 c. c. The urine does not appear to be eliminated constantly but periodically, as in the case of the higher forms. Since *Mustelus* dies in about an hour after immersion in fresh water, no attempt was made to collect the urine during such a short period. The effect of four other solutions, however, the osmotic effects of which have already been shown, were tried: namely, sea-water; concentrated sea-water having a Δ of 2.60° ; three-fourths sea-water plus one-fourth fresh water; and one-half fresh water plus one-half sea-water. For the first few hours after immersion the average secretion per hour for four specimens in sea-water was 0.4 c. c. urine; in the concentrated solution of sea-water, the average secretion of two fishes was 0.2 c. c. urine; in the solution of three-fourths sea-water plus one-fourth fresh water, the average secretion of two fishes was 1.2 c. c. urine; and in the solution of one-half sea-water plus one-half fresh water, the average secretion of five fishes was 1.4 c. c. urine. The results show that, in the concentrated solution of sea-water, less urine, and, in the dilute solutions, more urine is secreted than in normal sea-water. There is no doubt then that the immersion of the fish in modified solutions of sea-water with the resulting changes in the molecular concentration of the blood, causes an immediate reaction on the part of the kidneys.

The nature of the urine thus secreted as compared with normal urine is shown by the results of the following experiments: The Δ 's of the urine collected from three dog-fishes immersed in sea-water were respectively 1.69° , 1.70° and 1.77° . The average of these values is 1.72° . These results indicate that it may be hypotonic and not isotonic with the blood. Bottazzi ('06) stated that elasmobranch urine is isotonic with the blood, although some of the results given by him indicate that it is hypotonic. The Δ of the urine collected from a dog-fish immersed in a solution of

fresh water was found to be respectively 1.030 and 1.026. The specific gravity determinations were made on fresh urine. One sample was large enough for the use of the hydrometer. The other determinations were made with the pycnometer. Denis ('12) records the normal urine of one *Mustelus canis* as 1.032.

Finally, the average amount of chlorine in two samples of normal urine was 9.1812 gms. Cl per 1000 c. c. urine, whereas the chlorine in the urine of two other fishes immersed in a solution of one-half sea-water plus one-half fresh water for about four hours amounted to 6.9517 gms. Cl per 1000 c. c.

It must be concluded, therefore, that the urine collected from fishes immersed in diluted sea-water is more dilute than normal urine. What is the concentration of the blood under these experimental conditions? Are the activities of the kidneys such as to conserve in any way the osmotic pressure of the blood? In the specimen whose urine had a Δ of 1.61° after about four hours' immersion in one-half sea-water plus one-half fresh water, the Δ of the blood was 1.64° . The blood is slightly more concentrated than the urine; but it has already been shown that there is a great reduction in salts in the urine of the fish immersed in fresh water. This leads to the conclusion that the salts are not being excreted, but are being held back by the excretory organ. The kidneys are acting to maintain the osmotic pressure of the blood by the excretion of water. The problem is complicated by the fact that constantly water is coming into and salts are leaving the blood through the gills.

PRESENCE OF SALTS IN THE EXTERNAL MEDIUM AFTER THE IMMERSION OF FISHES IN DISTILLED WATER

If salts diffuse from the blood out through the gills, an analysis of the diluted sea-water in which *Mustelus* is immersed should reveal the presence of these salts. To test this I made the following experiment:

A male dog-fish 60 cm. long was pithed and a bolus of oiled cotton was placed at the entrance of the stomach to prevent regurgitation of the stomach contents. The fish was then immersed in sea-water. This was gradually changed to fresh water in about five minutes, when the fish was removed, thoroughly washed in fresh water and placed in a jar containing two liters of distilled water. No urine was allowed to enter the jar. Air was bubbled into this water during the course of the experiment. The fish was near death when taken out of the jar forty-five minutes later. The chlorine in one-half of this water was then determined in the following manner: The sample was boiled down to 200 c. c. and filtered; 20 c. c. of the filtrate was analyzed for chlorides by the Volhard method. This

was repeated five times. The average results equaled .0253 parts chlorine per 100. This is more than twenty times as much Cl as is present in the fresh water of Woods Hole. In a second experiment carried on in the same way, two fishes were immersed in four liters of fresh water. After death, the water was evaporated down to the volume of one liter and aliquot portions of this showed the presence of .68 gms. Cl in the water, or .01708 gms. chlorine per 100. This value is nearly twenty times the amount of chlorine found in the fresh water. In these experiments there were only two possible sources of the chlorides. One was the skin; but in view of the thorough washing of the external surface in fresh water this does not appear to me a probable source. The other was the gill membranes. Diffusion through these structures seems to afford the logical explanation of the presence of the salts in the water of immersion.

EFFECTS OF IMMERSION IN FRESH WATER ON BLOOD PRESSURE, RESPIRATION AND HEART BEAT

The effects of immersion on blood pressure are not so marked as on respiration and heart beat. In general, however, it can be said that from the time the fresh water is turned into the tank the blood pressure falls. The variations in blood pressure were recorded in the following manner: After a fish had been pithed, the tail was removed and a canula filled with a solution of sodium carbonate was inserted in the caudal artery. The fish was then placed in a tank of running sea-water. The canula was then connected with a recording tambour also filled with the sodium carbonate solution. The lever of the tambour recorded the blood pressure and the heart beats on a slowly moving drum. After a normal record had been obtained the fresh water was turned on. The fall in blood pressure varies in individuals, and appears to be correlated with respiratory rate and heart frequency. The blood pressure rises at times, but soon falls to its former level. This momentary variation is also connected with the variations in the heart beat. In three experiments at the time of death in fresh water, *i. e.*, when respiration had permanently ceased, there was a fall in blood pressure of about 30 per cent from the normal. Fig. 10 shows the change in blood pressure of *Mustelus* from the time of immersion in fresh water at 9.50 A. M. until its death at 11.15 A. M.

Immersion in fresh water results in the gradual cessation of respiration. For example, in one case there were 59 respirations per minute at the time when the sea-water was changed to fresh water; there were 61, four minutes after; 60, eight minutes after; 56, twenty-two minutes after; 46, thirty-one minutes after; 33, thirty-seven minutes after; 31, forty-two minutes after; 43 very feeble respirations, forty-eight minutes

after; 14, feeble, at fifty-five minutes; 8, very feeble, at sixty-seven minutes; after which the experiment stopped. In some cases, the diminution in respiratory rate toward death was still more marked. Moreover, the respiratory movements gradually became less forcible. Toward death, they were very weak and consisted of but gentle movements of the gill covers, to the eye ineffective as compared with normal respirations. The respiratory movements at times ceased for a period altogether and then suddenly broke forth with rapidity and force, soon fading, however, to

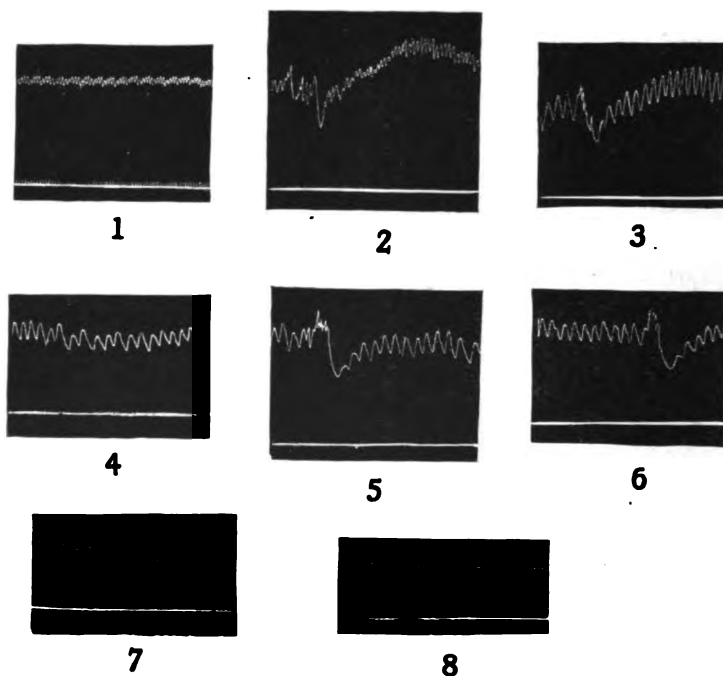


FIG. 10.—Showing changes in blood pressure of *Mustelus canis* due to immersion in fresh water

complete cessation. Respiration ceases before the heart stops. Now and then in normal respiration slightly convulsive movements of the gill apparatus is observable. These have been noted by Hyde ('04-'08) in the case of the skate. She drew the conclusion that these movements constitute an attempt on the part of the fish to force a sudden strong current of water through the gill apertures, the effect of which is to clean the gill membranes of any foreign matter collected from the sea-water during the course of normal respirations. After the fresh water was turned on, one

in intensity and frequency until nearly an hour after immersion, and then gradually and irregularly declined in number and strength. These respiratory movements are possibly modifications of increased intensity of the normal gill-cleaning movements mentioned above. It is also possible that both have fundamentally the same cause but that the stimulus is more intense when the fish is immersed in fresh water. Foreign ma-

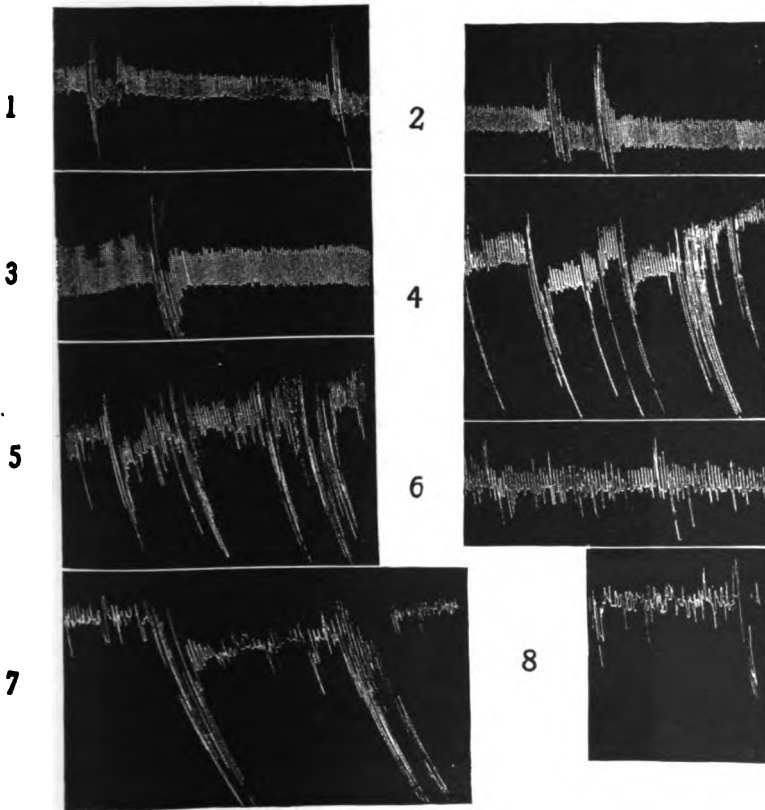


FIG. 11.—Showing the change in the character of the respirations during an hour after immersion of *Mustelus* in fresh water. Irregularities represent spasmodic respiratory movements.

terial on the surfaces of the gill membranes prevents the normal functioning of these structures and tends toward asphyxiation. The changes in the gill membranes brought about by immersion of the fish in fresh water are accompanied by the same convulsive gill movements.

There is considerable variation in the respiratory modifications in individuals, but the above mentioned features were observable in most

fishes studied. At times, the respiratory rate and heart frequency are equal; but they appear to be little correlated. After immersion in fresh water, there is rarely any sign of relation between the two rates. Fig. 11 shows the change in the character of the respirations due to the immersion of *Mustelus* in fresh water.

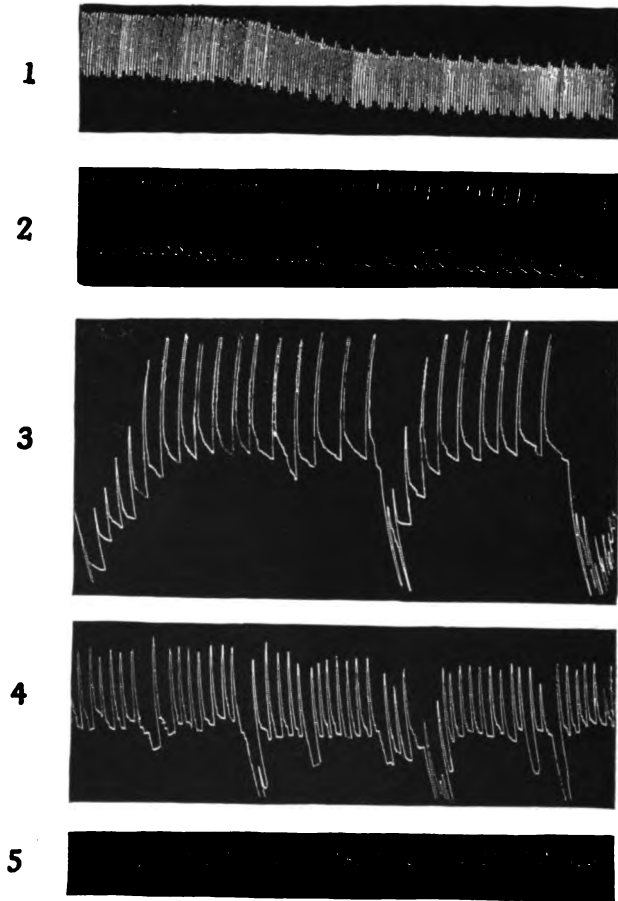


FIG. 12.—Showing changes in heart beat of *Mustelus* due to immersion of fish in fresh water. Irregularities represent spasmodic cardiac movements

The effect on the heart beat of the immersion of *Mustelus* in fresh water was studied directly in the following experiment, of which Fig. 12 is a record: A female *Mustelus canis* 79 cm. long, 1247 gms. in weight, was pithed and an opening about 1 cm. square was made in the pectoral arch over the pericardial cavity. A fine hook was attached to the tip of

the ventricle and connected by a thread to a lever recording on a slowly moving drum. With its dorsal surface downward the fish rested on an inclined support in a tank of sea-water so that the head and gills were under water. No sea-water entered the pericardial cavity. After the normal heart beat had been recorded for a few minutes, a stream of fresh water was turned into the tank, and a record was made of the changes in the heart beat for 80 minutes. During the period that the fish was immersed in sea-water, the heart was beating at the rate of 50 per minute. The rate changed to 59 per minute during the second minute after the fresh water had been turned on, and then gradually fell as follows: 6th minute, 45 beats per minute; 12th minute, 28 beats; 16th minute, 13 beats; 18th minute, 11 beats, 22nd minute, 9 beats; 30th minute, 10 beats; 35th minute, 6 beats; 44th minute, 14 beats; 51st minute, 12 beats; 58th minute, 13 beats; 70th minute, 15 beats; 75th minute, 14 beats; 80th minute, 12 beats. Accompanying the early diminution in heart rate, there was an increased amplitude of contraction. In fact, the amplitude of the beat varied for a time inversely with the rate. The increased amplitude and slower rate began to be marked about the 14th minute after the fresh water was turned on, coinciding somewhat with the time at which the water was entirely fresh, being most marked between the 30th and 40th minutes. A diminishing respiratory rate accompanied this increased amplitude of contraction. The forcible and slow heart beat gradually failed after respiration ceased. Soon after respiration ceased, the heart beat showed great irregularity in the time taken by each contraction. At the end of an hour, the amplitude of contraction was about equal to that of the normal heart beat but the rate was only about one-fourth as great. After this, the extent of the contraction diminished gradually, although by stimulating the heart mechanically it increased for a time. About 70-80 minutes after immersion in fresh water and about twenty minutes after respiration ceased, the heart beat, although slow and regular, was very weak and was probably not effective enough to drive the blood through the gill capillaries with sufficient rapidity to maintain life. This agrees in the main with Mosso's ('90) observation.

Another related feature accompanying the change in cardiac activity were the respiratory convulsions similar to those mentioned on page 57. This is strongly suggestive of an associated action of the bulbar cardiac and respiratory mechanisms which exists in the mammal. The gill covers

possibly an instance of reflex inhibition of the heart beat due to the cardiac-inhibitory center being stimulated by impulses from sensory nerves; but the heart gradually recovered the force and rate it had prior to the convulsive movement, and the respiratory spasm ceased.

During the twenty minutes after immersion, there occurred about ten very marked respiratory spasms with their accompanying effects on the heart. Twenty or more took place during the second twenty minute period. After this they diminished in number and force, ceasing almost entirely about the 70th minute. Some respiratory convulsions took place

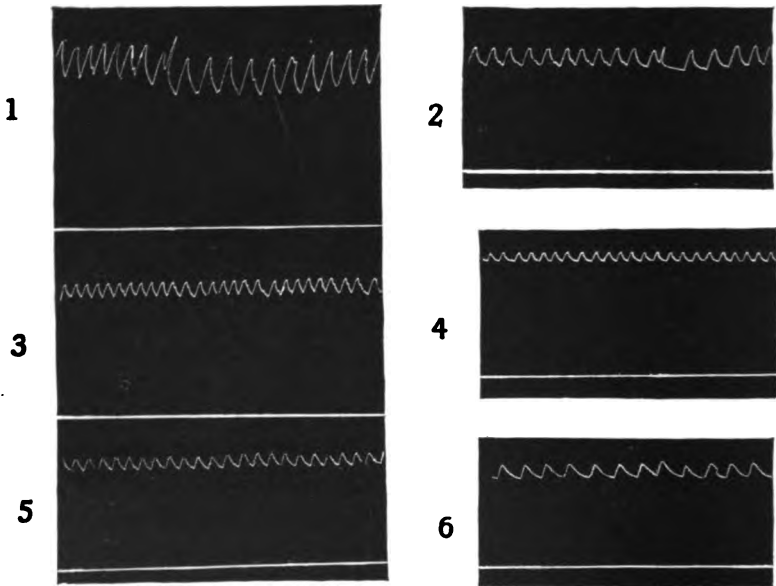


FIG. 13.—Showing changes in blood pressure and heart beat of *Squalus* due to transfer from harbor water to fresh water from 11.06 A. M. to 3.56 P. M.

after regular respirations had ceased. Fig. 12 shows the changes in the character of the heart beat of this specimen.

The case with *Squalus acanthias* studied at the New York Aquarium during the early winter, December, differs from that of *Mustelus*. The water in which these fishes had been kept had a temperature of about 12° C. Moreover, the fishes, as has already been described (p. 32), had been living in a diluted sea-water for some time. The rate of the heart and

of its blood pressure. This fell 30 per cent from its value at the beginning of the experiment. The fall was gradual. The heart was beating at the rate of 16 per minute at the beginning of the experiment and 8 per minute at the end. Respirations were at the rate of 14 per minute at the beginning and ceased about four hours after fresh water had been turned on. Fig. 13 shows the character of the changes in blood pressure and heart beat in this specimen. The absence of the spasmodic respiratory movements is apparent. Other spiny dog-fishes at the New York Aquarium did not withstand the immersion for so long a time. But in every case with *Squalus* the changes in blood pressure, respiratory rate and heart beat took place much more slowly than was the case with *Mustelus*. There are two factors that may have a causal connection with this difference. In the first place, because of its immersion in diluted sea-water during its stay in the aquarium, *Squalus* may have acquired a certain kind of immunity to the freshened water, so that a transition to wholly fresh water would not have such a quickly fatal effect as in the case of *Mustelus*. That the factor is not altogether the change in the osmotic pressure of the blood is suggested by the fact that after about an hour's immersion in fresh water the Δ of the blood of a number of spiny dog-fishes, as has been shown on page 33, was about the same as that of *Mustelus*, although it must be confessed not quite so high. In the second place, the temperature of the water in which the spiny dog-fishes had been kept as well as that of the fresh water in which the fishes were immersed in the experiment was low, the latter being 12° C. Metabolism was probably at a low ebb, and therefore chemical and physical changes would take place more slowly.

In publishing blood pressure tracings from the Chinook salmon, Greene ('05) states that certain waves, which are shown, are due to the rhythmical effect of respirations on the blood pressure which also records heart beats. A series of waves similar to those published by Greene are now and then found in the normal blood pressure tracing from *Mustelus* as shown by Fig. 10-1. In this case, it is certain that the waves are not all synchronous with the respirations, nor have the respirations anything to do with them. On the contrary, these are evidently Traube-Hering waves and probably due to rhythmical variations in the tone of the vaso-motor center. Almost as many respiratory movements take place during each of these rhythmical periods as there are heart beats recorded. It may be

respiration has ceased. The respiratory rate may suddenly increase temporarily, while the heart rate is steadily declining. On the other hand, the heart rate may become more frequent while the respiratory rate is declining.

Parker ('10) stated "that the rate of gill movement in the dog-fish depends upon the momentary state of movement of the animal. When resting, they vary from 35 to 40 movements per minute. When swim-

ming slowly, they respire 50 to 55 times per minute. In vigorous swimming, the rate is doubtless still more rapid." The accompanying figure, Fig. 14, is a record of the respiratory and cardiac activity taken simultaneously, and shows that while the respiration rate is 52 per minute the heart rate is but 40 per minute. At times, the two rates may be equal; but this is rather the exception, so far as my observation goes. The two seem to be independent.

We may conclude that the respiratory convulsions described above do not produce cardiac spasms as shown in Fig. 12, but, on the contrary, the two processes occur simultaneously and both have the same cause.

We know that the density of the water is changing constantly, but these spasmodic movements occur long after the water becomes fresh. The movements cannot be due to the stimulus of changing external density. We know, too, that the osmotic pressure of the blood is changing constantly; indeed, the change continues long after the water has become fresh and con-

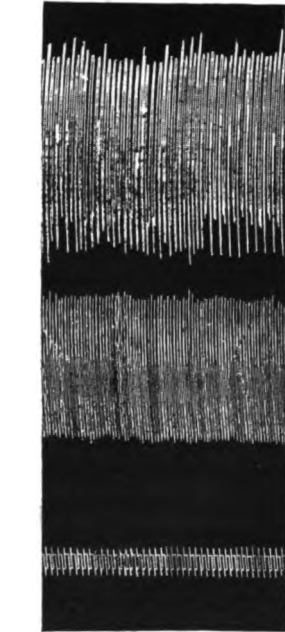


FIG. 14.—Comparative rate of respiration and heart beat in *Musculus* in sea-water. Upper tracing, heart beat, 40 per minute; below this, respiratory, rate, 52 per minute.

tinues to change up until the death of the animal. Owing to swelling corpuscles, dilution of the blood and alterations in the gill membranes, it is probable that the blood fails to get oxygenated and that its CO_2 increases in quantity. In fact, the blood drawn from the caudal artery at the end of the experiment has a dark appearance, brightening upon exposure to the air. If thus the blood becomes profoundly venous, laden with CO_2 it would flow through the respiratory center and cause spasmodic contractions of the respiratory muscles.

DISCUSSION

The changes in the osmotic pressure of the blood of *Mustelus canis* after immersion in diluted and concentrated solutions of sea-water have been shown in the preceding pages. It has been shown that this dog-fish differs from the marine invertebrates in that the osmotic pressure of its blood does not become equal to that of the surrounding medium, when this differs in its concentration from the sea-water. Moreover, when a considerable change has been produced in the osmotic pressure of the blood of *Mustelus* by immersion in a modified solution of sea-water, the normal osmotic pressure of the blood is not regained on the return to sea-water. In this respect, also, the elasmobranch differs from the marine invertebrate.

The elasmobranchs differ also from the marine teleosts, the osmotic pressure of whose blood is between one-third and one-half that of the external medium, and whose blood maintains a constant osmotic pressure despite marked changes in the osmotic pressure of the external medium. The elasmobranchs cannot in truth be termed either poikilosmotic or homoiosmotic animals. It has been shown that the freezing point of the blood rises about 0.40° C. on immersion in fresh water until near death, and 0.18° C. on immersion in sea-water diluted with an equal volume of fresh water, having a freezing point of -1.00° . In both cases the change in the osmotic pressure of the blood is about one-fourth of the change in the external medium. In concentrated sea-water having a freezing point of about -2.60° , or about 0.80° below that of sea-water, the osmotic pressure of the blood increases about one-fourth as much as the change in the external medium. In these three cases, the change in the osmotic pressure of the blood though not equal to the change in the osmotic pressure of the external medium, yet bears a rather constant ratio to the external change.

This appears to be the index of a certain degree of independence on the part of the animal of the osmotic pressure of the external medium. From this point of view, it would be correct to consider the elasmobranchs as occupying a position midway between the marine teleosts and the marine invertebrates as to the relations of the osmotic pressure of the internal fluids of the body to the external fluids in which these forms live.

The problem, however, calls for further analysis. In the first place, it is necessary to know what parts of the elasmobranch body are concerned in the osmotic changes which cause the death of the animal in the modified external medium. Evidence has been presented showing that there

are two gateways between the internal media and the external medium, namely, the gill membranes and the kidneys. After immersion of *Mustelus* in diluted sea-water, of course all movement of liquids in the case of the kidneys must be from within outward; in the case of the gill membranes the movement may be in both directions.

Information has been gathered from the experiments as to the condition of the blood due to immersion of the fish in the modified sea-water. In fresh water, the specific gravity of the blood is less than normal; the solids are 14.8 per cent less; the nitrogenous substances 15.6 per cent less; the urea content has decreased 15.5 per cent; the chlorine content is 25.7 per cent less and the osmotic pressure has fallen 22 per cent. When hypertonic saline solutions are introduced into the blood system of an animal, one of the first reactions is the withdrawal of water from the tissues into the blood; but the present condition is the reverse. The blood is deficient in salts. The tendency of the tissues will be to absorb water from the blood. Evidence of this reaction has been presented on page 52. But sufficient water cannot be taken into the tissues to counteract the constant inflowing of water from the exterior. Even before the tissues have begun to take up water, it is probable that the kidneys, stimulated by the modified diluted blood, react in such a way as to cause an increased secretion of water. The urine formed under these conditions has a lower specific gravity, lower osmotic pressure and lower chlorine content than the normal urine. Moreover, the quantity of urine secreted is in excess of the normal quantity. It is possible that the excessive secretion of urine is due in the last analysis to an increased amount of water in the blood flowing through the capillaries of the kidney. If any considerable quantity of water has entered, there must have been a readjustment of the caliber of the blood vessels, since no marked increase in blood pressure can be detected. Baglioni called attention to the fact that when almost all the blood was withdrawn from an elasmobranch *Scyllium*, in a short time the blood contained almost the normal percentage of urea, although it had a lower osmotic pressure than normally. Moreover, he found that a starving *Scyllium* also exhibits a tendency to retain its urea. It appears therefore that the cells of the kidney are capable of retaining to a certain degree the urea as well as the salts. It appears probable that the dog-fish possesses a mechanism for the regulation of the osmotic pressure of its blood which is efficacious in the case of slightly diluted external media.

I have shown, however, that at the time of death of *Mustelus* in fresh water there is a deficiency of 15.5 per cent in urea and other nitrogenous substances of the blood which I claim to be largely due to dilution of the

blood. The chlorine of the blood has decreased nearly 26 per cent. This probably means an excessive loss in salts, which would account for the greater decrease in the osmotic pressure of the blood.

We may next consider the contribution of the salts and urea to the osmotic pressure of the blood. The usual impression one gets from a perusal of the literature is that the osmotic pressure of the blood is due almost wholly to the presence of crystalloids, *i. e.*, chlorides and urea. By the method of ashing, it is probable that some small part of the chlorine is lost by volatilization. In the method used above for the determination of the chlorine in serum, it is possible that a certain amount of salts was retained by the diffusates. Nevertheless, every care was taken to prevent error in the analyses. The determination of the urea was likewise as carefully made. Dakin ('08) found that the blood of *Acanthias vulgaris*, the freezing point of which is almost identical with that of *Mustelus*, contained 0.88 per cent chlorine. The serum of *Mustelus* blood contains, according to my analyses, 0.86 per cent chlorine. Expressed in terms of sodium chloride, this means that there was present 1.424 per cent NaCl. The urea formed 1.55 per cent of the blood (*i. e.*, corpuscles and plasma). This is somewhat greater than the percentage of salts. In the analyses given by other investigators, a greater amount of urea than salts was also found. Moreover, when one takes into consideration the differences in the osmotic pressure of the sea-water at the stations where other investigations have been made, knowing selachian blood to be approximately isotonic with its sea-water medium, one finds that the change in the percentage composition of the salts and the urea is proportional to the modification of the osmotic pressure of the external medium.

By analysis, it was found that 1.55 per cent of the blood, plasma and corpuscles is urea. This means that the urea constitutes 1.94 per cent of the serum, which is equal to a 0.32 gram molecular solution. Since the freezing point of a gram molecular solution is -1.84° (Nernst, '09) a 0.32 solution would have a freezing point of about -0.59° . This amount represents the lowering of the freezing point of the blood due to urea. The salts present in the blood are, however, equivalent to a 0.24 gram molecular solution of sodium chloride. This, allowing for dissociation, has a freezing point of -0.85° . This represents the lowering of the freezing point due to the inorganic salts of the blood. The sum of 0.59° and 0.85° , or 1.44° , represents the lowering of the freezing point

counted for. Macallum ('10) found that the urea and salts of the serum of *Acanthias vulgaris* would not account for its freezing point. He concluded that the difference between the freezing point of serum and that produced by the combined salts and urea was due to the other organic solutes. These were found to be ammonia salts, which were present in amounts sufficient to account for the additional depression of the freezing point. We may infer that ammonia salts are present in the blood of *Mustelus*. By these and other organic solutes, such as sugar, the freezing point of the blood is brought to -1.87° . The rôle of these substances, which are also crystalloids, has been too much neglected.

Mines ('12) described the effects of electrolytes on the elasmobranch heart. The work was done at the laboratory of the Marine Biological Laboratory at Plymouth, England. The normal freezing point of the forms used was probably similar to that of *Mustelus*, namely, -1.87° . Records were made showing the effects of solutions perfusing the heart. The fluid was adapted from one used successfully by Knowlton, whose results have not as yet been published. From the formula given by him, I conclude that Mines's solution must have had a freezing point less than -1.52° . In other words, the solution was hypotonic to the blood which normally bathed the heart. It contained about the same percentage composition of metallic elements (sodium, potassium, calcium and magnesium) as determined by Macallum, and urea and chlorides as determined by myself. Since each of the kations has been shown by Mines to have a specific effect on the heart action, his perfusion solution probably contained the optimum amount of these substances. Baglioni's experiments on the maintenance of the heart beat of elasmobranchs were carried on at Naples, where the mean freezing point of elasmobranch blood is -2.29° . The author used two solutions, one being a 3.5 per cent solution of sodium chloride, which is isotonic with the blood. The other solution consisted of 2 per cent sodium chloride + 2.2 per cent urea plus a trace of calcium chloride. The computed freezing point of such a solution is about -2.00° . The freezing point of a solution of 2 per cent urea + 2 per cent NaCl obtained by means of the Beckmann apparatus is about 1.80° . Hence the solution with which Baglioni obtained his results was in all probability somewhat hypotonic to the blood of the elasmobranchs he used.

If we subtract from the normal freezing point of the blood, the freezing point due to the salts, *i. e.*, about -0.85° , there is a remainder of -1.02° which is caused by urea and other substances in solution. It has been noted that when the fish is immersed in fresh water, the nitrogenous

of the blood should undergo a similar reduction of 15.5 per cent of -1.02° , or 0.158° . If the salts are diluted to the same extent as the organic substances, there should be an additional rise in the freezing point equal to 15.5 per cent of -0.85° , or -0.132° . This would make the total change in the freezing point of the blood due to immersion in fresh water equal to 0.29° , but, as a matter of fact, a rise of 0.408° was noted on page 14. In other words, the change in the freezing point due to dilution alone does not account for the maximum change observed by actual experiment. How can the remainder of the change be accounted for?

The total loss in chlorine and probably in salts from the serum has been shown to be 25.7 per cent. In the preceding paragraph, 15.5 per cent of this loss has been ascribed to dilution. There remains 10.2 per cent, or -0.087° , which I conclude represents the amount lost by diffusion through the gill membranes. If 0.29° rise in the freezing point be due to dilution, and a further rise of 0.087° be due to diffusion, the two values combined account for a total rise of 0.377° . The observed rise was 0.408° .

Dakin ('08) in discussing work of a similar nature wrote, "Another interesting point in the above results is that reduction in salt contents of the blood as indicated by the chlorine contents is much greater than the lowering of the osmotic pressure would lead one to expect." This can now be explained in the following manner: If the loss in salts had been equal to the loss in organic substances then the percentage change in the freezing point would have been equal to the percentage change in these other substances. Since, however, the change in the salts is in excess of the change in the other substances, it follows that the percentage change in the freezing point of the blood is somewhat greater than the percentage change due to organic solutes and somewhat less than the percentage change in the salts. This is shown by the data. Thus there was a loss of 15.5 per cent in organic solutes, a loss of 25.7 per cent in salts, but only a loss of 21.9 per cent in the osmotic pressure of the blood. Hence, not only do the calculations of the change in the freezing point of the blood based on the results of chemical analysis confirm the general result ascertained, by the direct determination of the freezing point, but it is also possible to gain further insight into the nature of the changes produced.

It has been found that the blood is but slightly laked even at the time of death. At the same time the ratio of the volume of

rule are swollen, a small number burst. In the swollen state it is possible that their oxygenating function is interfered with. This would also partially explain the effect on respiration.

At death in fresh water, the plasma is deficient in urea. Baglioni and Mines have shown that urea is a necessary ingredient of the selachian blood for the maintenance of normal cardiac activities. Baglioni concluded that it promoted systolic tonus. He found that other substances, such as cane sugar, cannot replace it, and that therefore urea is necessary for its chemical effect on heart tissue rather than for its osmotic contribution.

The deficiency of the blood in salts, however, is greater than in urea. Baglioni concluded that the sodium salts increase diastolic tonus. He found that an equal increase in urea and sodium chloride causes an increase in systolic and diastolic tonus up to a certain point beyond which cardiac activities come to a standstill. He concluded that in the proportions in which the salts are found in the blood, systolic tonus counteracted diastolic tonus and the interaction of the two was necessary for normal rhythmical contraction. It has been shown in the present paper that the balance normally present between these two substances is upset, for the blood is losing salts more rapidly than its urea. Loeb ('11) has called attention to the rôle of the salts of sodium, potassium, calcium and magnesium in the preservation of life. He has maintained the importance of the proportion in which they exist in sea-water. The same proportion of the same salts has been found by Macallum ('10) in the blood of animals representing different phyla. It has been shown in the present paper that the salts diffuse out through the gill membranes, and it is possible that the different ions pass out at different rates. Thus the sodium and magnesium ions may pass out first of all because of their speed of diffusion, and the potassium and calcium may pass out to a smaller extent and later. Thus the normal relations of these ions so necessary to the normal heart beat and to the activities of all tissues may be thus changed. A more rapid loss of salts on the part of the blood than on the part of the tissues leads to a disparity between the osmotic pressures of the two. The tissues absorb water, as shown, leading to an œdema. This interferes with their normal action—as, for example, the water rigor of muscle.

The marine invertebrates, because of the lack of a quickly acting regulative mechanism, are helpless in the event of a rapid change in the molecular concentration of the external medium. Though their organs

have migrated into fresh water. Such a regulative mechanism is one of the mechanisms of adaptation.

The dog-fishes, on the other hand, are migratory. I think it probable that they are provided with a sensory apparatus by which they are made aware of marked decreases in the concentration of the sea-water, with the result that they avoid dilute media. The dog-fishes are provided in addition with an excretory apparatus which is able to regulate to a modified extent the osmotic pressure of the blood. The result of this activity of the kidneys is that the change in the osmotic pressure of the blood is always less than the change in the external medium. The kidneys conserve those substances which contribute to the molecular concentration of the blood and eliminate the excess of water. There is a limit, however, to this life-saving action of the kidney.

The effect of a stimulus depends not only upon its intensity but also upon the suddenness of it. Osmotic changes are induced more rapidly by a sudden than by a gradual change from sea-water to fresh water. In fact, in my experiments a sudden great change in the osmotic pressure of the external medium sometimes caused a rupture of the gill membrane at certain points with a resulting flow of blood. The gradual transition from sea-water to fresh water prevented this bleeding from the gills. Death occurs more quickly in such cases without a great change in the osmotic pressure of the blood. These are simply instances of a wider application of Du Bois Raymond's law of stimulation. But it has been shown (p. 28) that the osmotic change occurs through the gill membranes. These, however, are not strongly resistant to changes in the osmotic pressure of the external medium.

The reason that the dog-fish can withstand moderate changes in the external medium is not because it resists these perfectly, but because the organization of its protoplasm is of such a nature that life activities can continue even though the osmotic character of its blood is considerably modified. The heart of *Mustelus* continues to beat long after respiration has ceased after immersion in fresh water. *Squalus* and other elasmobranchs live in the dilute sea-water at the New York Aquarium; and yet the osmotic pressure of the blood of *Squalus*, while considerably above that of the harbor water, is still but nine-tenths of that found in fishes living in sea-water. The osmotic pressure of the blood of higher forms never has been proportionately reduced without serious impairment if not cessation of protoplasmic activities.

Moore ('08), in advancing strong arguments to show the failure of the membrane theory to account for the equilibrium between the cell and its environment, suggested that the cell was able to undergo reversible proc-

esses of association and dissociation with the constituents outside of it. Such association is in the nature of more or less stable chemical combinations which he terms adsorpates. For each cell there is a range of osmotic pressure within which partial association and dissociation is possible, and within this range labile exchanges are possible.

This idea may be extended to explain why the tissues of the dog-fish, though normally adapted to an osmotic pressure of its blood approximately equal to that of the sea-water, is able to live in the dilute sea-water of New York harbor. In such dilute water, the blood has an osmotic pressure represented by a freezing point of -1.70° . This represents the lowest osmotic limit of the blood at which the cells of the dog-fish can establish proper associations with the substances in the blood, or in other words at which the metabolic processes can take place. It is of interest to note that this freezing point, namely, -1.70° , is also the least noted in the case of the smooth dog-fish, *Mustelus*, at Woods Hole (see p. 7). Continuing Moore's conception, it is probable that -1.87° represents the optimum osmotic pressure at which the labile processes of association and dissociation can most perfectly take place. Greene ('05) implies the same idea, for he concludes that salmon having blood with an osmotic pressure widely different from the mean are in a pathological condition. Dakin ('08), Dekhuyzen ('04) and others who have determined the freezing points of teleost blood seem impelled to insist on its constancy; yet considerable variation appears in the actual results noted by them. Variations occur even in human blood at different times of day, as shown on page 6. Winter ('96) has maintained that metabolic processes would cease if the osmotic pressure of the blood should attain a stagnant dead level.

It should be observed in this connection that the freezing point of the blood of the dog-fish at the New York Aquarium remains at about -1.70° , while the water in which they live has a freezing point of about -1.00° . The animal is able to prevent a further lowering in the osmotic pressure of the blood. It cannot resist perfectly the change in the osmotic pressure of the external medium, but it is able to carry on life processes at the lower limit. It is possible to conceive that because of the dilute condition of the blood, the cell finds great difficulty in establishing normally stable associations. Life processes are continued, but with decreased efficiency. Indeed observation shows that the elasmobranchs at

time of death in fresh water. In fact, the change in the osmotic pressure of the blood due to dilution alone would cause a rise in the freezing point of the blood of about 0.30° . Therefore, mere dilution of the blood up to the point at which salts begin to diffuse out would pass the limit in the range in the osmotic pressures of the blood and cause death. This explains why the dog-fish failed to regain the normal freezing point of its blood on return to sea-water after a change of about 0.30° due to immersion in fresh water. Because of such a reduction in the osmotic pressure of the blood the constitution of the protoplasmic molecules is disturbed in part, and on the return to sea-water the normal relations fail to be regained.

CONCLUSIONS

The following conclusions regarding the osmotic relations of *Mustelus canis* seem to be warranted:

The osmotic pressure of the blood of the fish varies about an optimum represented by a freezing point of -1.87° .

The change in the osmotic pressure of the blood due to changes in the molecular concentration of the external medium depends,

1st, upon the time of immersion in the external medium, and,

2nd, upon the modification in the molecular concentration of the external medium.

The change in the osmotic pressure of the blood is not equal, but yet bears quite a constant ratio to the change in the molecular concentration of the external medium. The blood of *Squalus* living in brackish water has a higher osmotic pressure than that of the water in which it lives.

When a considerable modification in the osmotic pressure of the blood is brought about by immersion of the fish in solutions hypotonic or hypertonic to sea-water, the normal osmotic pressure of the blood is not regained by the return of the fish to sea-water.

The changes in the osmotic pressure of the blood take place through the gill membranes.

The osmotic pressure of the blood is not greatly modified by the abstraction of one-half the total quantity of blood in the body.

Although the blood is but faintly laked on immersion of the fish in fresh water, the corpuscles are swollen.

The resistance of the erythrocytes of elasmobranchs to hæmolysis is not much inferior to that of the marine teleosts and appears to be independent of osmotic relations of the corpuscles to its surrounding medium.

When *Mustelus* is immersed in hypertonic solutions of sea-water, not only does the osmotic pressure of the blood increase but also its chlorine content.

The specific gravity of the blood decreases on immersion of the fish in fresh water.

When the fish is immersed in fresh water, a certain amount of decrease in the osmotic pressure of the blood can be ascribed to dilution of the blood caused by the absorption of water through the gill membranes. In addition, a further change is due to diffusion of salts outward through the gill membranes, as is shown by the presence of considerable quantities of chlorine in the water in which the fish is immersed.

The tissues of the body tend to maintain the osmotic pressure of the blood by absorbing water from the hypotonic blood and this tends to raise the pressure.

By secreting rapidly a diluted urine, the kidneys also tend to maintain the normal osmotic pressure of the blood. By this process, the urea and a certain amount of the salts of the blood are conserved.

The changes in blood pressure due to immersion in fresh water are slight as compared with the effects upon respiratory and cardiac activity.

On immersion in fresh water, there is a gradual failure of respiration: this is marked by irregularly repeated spasmodic respiratory movements which increase in intensity for a period and then decline.

When the sea-water in which the fish is immersed is gradually changed to fresh water, the heart beat increases in amplitude and decreases in rate. The contractions gradually diminish in force, although the heart continues to beat faintly after respiration has ceased.

Coincident with and similar in character to the spasmodic movements of respiration, spasmodic contractions of the heart occur.

The normal osmotic pressure of the blood of *Mustelus* is maintained only by the organism remaining in sea-water. It is probably provided with a sensory apparatus by which it is able to avoid great modifications of the external medium. In slightly brackish waters, the osmotic pressure of the blood is diminished by the influx of water through the gill membranes; but because of the regulative activity of the kidneys and other bodily tissues, the changes are less than the changes in the external medium, and are still within the range of pressures compatible with life. With greater changes in the molecular concentration of the external medium the organism succumbs.

The gill membranes are probably not greatly injured by this absorption of water, for the animal continues to live indefinitely, as is shown by the elasmobranchs in the New York Aquarium. It may be concluded that

the death of *Mustelus* is due to the following effects produced by immersion in fresh water: increased permeability of gill membranes; dilution of the blood; swelling of corpuscles; partial hæmolysis; excessive loss of salts from the blood; a fall of nearly one-fourth in the osmotic pressure of the blood; an associated cedema of the tissues, and a failure of respiratory and cardiac activities.

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A CONTRIBUTION TO THE GEOLOGY OF
THE WASATCH MOUNTAINS, UTAH

BY

FERDINAND FRIIS HINTZE, JR.



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BY FERDINAND FRIIS HINTZE, JR.

(*Read by title before the Academy, 5 May, 1913*)

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INTRODUCTION

The general geological features of the Wasatch Mountains have long been known from the comprehensive reports of the early federal surveys. Since these general studies were made, several special problems have been investigated, with the result that many new facts have been added, in the light of which, many of the first conceptions have been greatly modified.

One of the most important of these later observations is concerned with the structure. The complicated tectonic features of this remarkable range are only now beginning to be appreciated. The finding of large overthrusts in the vicinity of Ogden by Blackwelder in 1909 and the tracing of the great Bannock thrust from southern Idaho south into the Wasatch range accomplished by Richards and Mansfield of the U. S. Geological Survey within the last year or two have added much importance to this phase of the structure. Boutwell had previously discovered overthrusts in the Park City district, but they were thought to be local features and were not greatly emphasized.

As might be expected, the unravelling of the structure has had an important bearing upon the stratigraphy of the range, especially since the regions in which the overthrusts have been found were those that furnished the type sections to the early workers. The repetition of beds brought about by overthrusting escaped the attention of the Fortieth Parallel geologists, who gave the first unified account of the stratigraphy, and their section is therefore subject to correction.

It is the purpose of the writer to present in this paper a number of facts that were observed in the summer of 1912 in the central part of the Wasatch range, particularly in Big and Little Cottonwood Canyons, and to discuss the structure and stratigraphy of that region. The discovery of a great overthrust at Alta, in Little Cottonwood Canyon, has

led to a new conception of the stratigraphy as well as the structure of this part of the range. The finding of many new fossil species has shed important light on the age of the paleozoic rocks, and the discovery of several disconformities has enabled the writer to subdivide the series into several new formations. Observations on the physiographic features of the central Wasatch have afforded interesting results on the present state of dissection of the Wasatch block mountain and have suggested an explanation of the principal drainage lines of the region. Other problems are partly solved, and much work will still have to be done before a complete account of the many interesting geological phenomena here shown can be given.

The writer desires to thank the mining men of South Fork and Alta most heartily for the support and assistance which they generously extended to him during his field work. While it does not seem possible to mention the names of all who have rendered help, the writer cannot forbear to acknowledge the cordial treatment shown him by Mr. Green of the Tar Baby Mining Company and Mr. Barney of the Cardiff Mining Company in South Fork, and at Alta by Mr. Blake of the Columbus Consolidated, Mr. Lemmon of the Columbus Extension, Mr. Jacobson of the Alta Consolidated, Mr. Godbe and Mr. Burton of the Michigan Utah, Mr. Gabrielson of the South Hecla and Mr. Stillwell of the Emma. To the managers and directors of these mines, the writer is grateful for the privilege of visiting the various properties and studying the ore deposits.

To the several members of the Department of Geology at Columbia, the writer feels greatly indebted for many helpful suggestions in the preparation of the report. To Professor Amadeus W. Grabau is due special thanks for the encouragement he has given from the very outset. Throughout the laboratory work, and especially on the paleontologic and stratigraphic side, he has manifested great interest in the results as they appeared. His kindly criticism has been of much value and assistance in formulating the conclusions here drawn. To Professors D. W. Johnson and C. P. Berkey, the writer is indebted for many valuable criticisms relative to the physiographic and petrographic features of the work.

PHYSIOGRAPHY

ORIGIN OF THE WASATCH MOUNTAINS

Immediately following Cretaceous time, the present Great Basin province was the scene of dynamic disturbances through which numerous

and the surface was reduced to an aspect of low relief. Then followed a period marked by profound faulting, the lines of movement being principally in a north-south direction, but with many cross fractures, which resulted in the formation of great fault-block mountains. These were characterized by relatively simple external features but with complex internal structure. The most easterly, and one of the most continuous of these fault-block masses, is the present Wasatch range.

When newly formed, the Wasatch block had a steep western face and a long gentle eastern back slope. It was greatly elongated in a north-south direction, extending from central Utah northward for almost 200 miles. The width as measured from its fault face on the west to its eastern border was about 25 miles. Its height was mainly due to vertical displacement along the great fracture line on the west. This dimension was no doubt cumulative and due to periodic uplift, the aggregate throw probably reaching 10,000 feet. The line of greatest elevation or crest of the block was near the western margin.

DISSECTION AND DRAINAGE

The dissection of such a block must have been initiated by the consequent streams which flowed down the two unequal slopes to the east and west. The valleys developed by these opposed streams would thus be transverse to the principal direction of the range, and when fully developed would divide it into a series of roughly parallel east-west ridges on each slope, leading from the main divide to the two margins of the block mountain. The unequal declivity of the two sets of streams would in time cause a migration of the divide toward the center line of the block, if the structure and materials were not essentially different and the base levels were at the same elevation on both sides. If the base level on the east were higher than the one on the west, the divide would come to rest nearer the eastern border, and the valleys and ridges west of it would be longest and most prominent. Some of the most powerful streams on the west slope might even cut entirely through the divide and send out lateral subsequent tributaries that would capture the east flowing consequents and lead them westward into the Salt Lake Basin. When once established, these master streams would continue to push eastward into the region beyond the Wasatch, gradually acquiring more and more drainage territory.

In the light of these theoretical considerations, we may examine the present maturely dissected Wasatch block mountain for some of the larger features due to its original form and subsequent dissection.

The main crest line of the Wasatch extends in a general north-south direction and stands at a variable height of from 3000 to 8000 feet above the level of the Bonneville Basin to the west. It is situated near the western border of the block and is marked by a succession of lofty peaks which crown the western terminations of a series of ragged ridges that lead westward from the main divide. This divide is situated from two to six miles east of the crest line, being often nearer the eastern border of the range than the western. This is especially noticeable in the central Wasatch. Here the divide is also lower than the crest by more than a thousand feet.

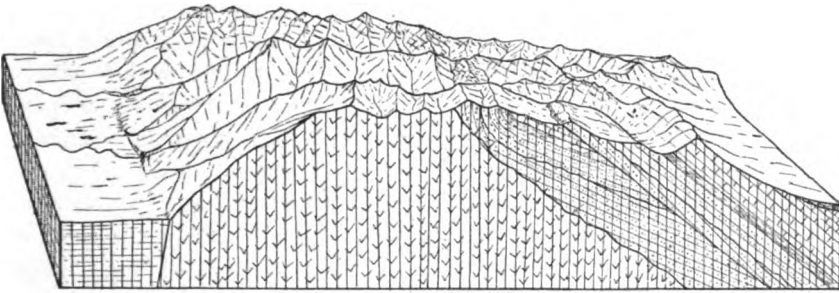


FIG. 1. STEREOGRAM OF A PORTION OF THE CENTRAL WASATCH MOUNTAINS, UTAH

Shows a maturely dissected block mountain with a steep western fault face and a gentle eastward back-slope. The main gorges are Big and Little Cottonwood Canyons, heading near the eastern margin of the block, and representing principally obsequent stream channels.

To the east, a similar series of ridges and intervening gorges lead off from the divide. A significant difference is to be noted here between the slope of the tops of the ridges east of the divide and those to the west. East of the divide, the ridges slope down to the level of high-lying basins, while westward they rise to the crest line and then suddenly break off to the Salt Lake plain. The tops of the ridges from the crest eastward descend gradually to the divide, and, crossing over it, they continue to become lower until they reach the eastern valley levels. They thus indicate the original back slope of the block, though they do not preserve any of the undissected upland surface. The present eastward slope of the ridge tops is not a very noticeable feature when viewed from the high peaks on the crest, the inclination being but a few degrees and appearing

The migration of the divide from the crest line toward the eastern margin of the block is most pronounced in the central part of the range. Big and Little Cottonwood canyons are good examples of long and deep valleys pushed back from the western face of the range well toward its eastern margin. The streams which have cut them have a more direct course to the base level of the region than those on the opposite side of the divide. This advantage has enabled them to send the divide east of the center line, where it should be expected to come to rest if the stream grades were equal in both directions (see Fig. 1).

At present, the Salt Lake Basin is the base level for the drainage of the east slopes as well as the west. The two through going streams, the Provo and Weber Rivers, bring the eastern drainage by long round-about courses back into the Bonneville Basin. No special field work has been done by the writer to determine the conditions which have established these streams in their present courses, but the thought suggests itself very strongly that they began as Big and Little Cottonwood creeks did to cut headward, and being more successful penetrated far enough to capture all of the eastern drainage of the central Wasatch and much of the western Uintas and the plateau region to the north and south of the Uintas. Their headwaters approach each other very closely at the western end of the Uinta uplift and are here separated by a low divide near the southern limit of the Kamas prairie. This divide becomes more pronounced as we follow it westward, rising as a high ridge between Parley's Park and Provo, or Heber Valley, and eventually culminating in Clayton Peak on the Wasatch divide, at the head of Big Cottonwood Canyon. The eastern slope of the Wasatch in this neighborhood is thus drained by two river systems which lead off in opposite directions, at length turning westward and cutting across the Wasatch to the Bonneville Basin. The small consequent streams which lead north-east and south-east from the Wasatch divide on opposite sides of Clayton Peak have the disadvantage of a long detour to the base level and have therefore been unable to cope with the streams west of the divide which have a much shorter and more direct course to the same base.

Structure and hardness of the rocks seem to have exercised only a minor amount of control in the determination of the position of the stream channels west of the divide. In Big Cottonwood Canyon, where the hardest rocks of the region are exposed, the stream seems to have cut indifferently across the beds in a peculiar diagonal fashion in the lower half of its course. In the upper half, it has much less fall and follows the strike of the beds more closely. The rocks here are limestones, shales

and sandstones, while in the lower and steeper part of the canyon they pass into hard quartzites and slates.

It thus seems to be a fact that the structure and hardness of the rocks in the upper part of the canyon have had a somewhat greater influence on the course of the stream than in the lower part. Little Cottonwood Canyon is developed for the most part in granite of a very hard and homogeneous character. The course of the canyon is parallel to Big Cottonwood, where both structure and heterogeneous rocks enter into the problem. It is apparent that there must be some other cause operative to produce the correspondence. The chief determining factor seems to have been the original form of the block mountain. The western consequent streams on the steep fault face developed their channels transverse to the main north-south trend of the block, their direction being determined by the slope primarily. If the block was rapidly uplifted, the high gradient of the streams would be quite sufficient to cause them to cut back independent of the structure and kinds of rock. The direction of back-cutting would be at right angles to the front of the block, and as this was somewhat irregular, being curved in places, the stream courses should show some irregularity in direction. This indeed is the case. Where the fault face forms a great curve, as it does southeast of Salt Lake City, the canyons show a marked tendency to take off in the direction of the extended radii of the arc, as should be expected.

GLACIATION

After the Wasatch block mountain had been maturely dissected by stream action as briefly outlined above, Alpine glaciation set in during the Pleistocene period. Many of the deep V-shaped gorges were hollowed out into broad U-shaped valleys of striking outline. The best known example is Little Cottonwood, but there are many others in the upper parts of the large canyons. The upper half of Big Cottonwood is a deep U-trough with many hanging valleys on both sides. The heads of the canyons were widened into broad catchment basins with steepened sides. The divides were greatly sharpened in many places. Altogether, the topography was modified to a considerable extent in the central Wasatch, especially at the higher elevations near the heads of the canyons.² Numerous lakes due to glacial damming and the plucking action of the ice by which rock basins of considerable depth were formed are to be found at the heads of the larger canyons. Good examples of *roche moutonnées*,

² For a map showing the location of the principal glaciers and their catchment basins, as well as a brief account of the glaciation in the Wasatch, see ATWOOD: U. S. Geol. Surv. Prof. Pap. No. 61.

rock steps, and various other features due to glaciation are of frequent occurrence (see Plate I, Fig. A).

Since the disappearance of the glaciers, erosion has been slight. The streams have cut through the loose moraines in some places, but where they have been flowing on solid rock beds, they have cut but faint notches. These modifications are negligible as compared with the preglacial and glacial erosion which produced mature dissection.

STRATIGRAPHY

INTRODUCTORY STATEMENT

The first works of importance on the general stratigraphical succession in the Wasatch Mountains are those of the King³ and Hayden⁴ surveys in the late seventies. They are to-day the only comprehensive account that we have dealing with the great range of sediments there exposed. Being general in their treatment, they have left many details to be supplied by closer investigations, such as are carried on within smaller quadrangles where the necessary time is taken to work out structural problems as well as to observe the general sequence of beds. American stratigraphy offers many examples of the mistakes that are so easily made by following the law of superposition without due regard to structure. Unrecognized repetition of beds by folding and faulting has often led to serious errors in estimating the real thickness and succession of formations. Within the limited time that was allotted to the comparatively few workers on these early surveys, a wonderful amount of field work was done, and magnificent reports, well illustrated with maps and sketches, were issued, which, though they are now known to be wrong in many cases, still serve as the best introduction to the systematic geology of the range.

In presenting a generalized account of the stratigraphy of the Wasatch Mountains, the Fortieth Parallel geologists seem to have taken the sections which showed the thickest development of the rocks of the various systems. The sections exposed in Weber Canyon and a few miles to the north in Ogden Canyon, together with those found in Big and Little Cottonwood Canyons, sixty miles to the south, seem to have been chosen

and Parley's Park, the most extended and instructive stratigraphic exhibition of the Paleozoic series in the Fortieth Parallel area." ⁵

It now appears that the Ogden area, recently visited by Blackwelder⁶ and some of his colleagues from the University of Wisconsin, and the Cottonwood Canyon district, covered by the writer last summer, are similarly characterized by complicated structures involving large overthrusts which duplicate the rocks of the lower members of the Paleozoic series and give an apparent thickness which is much too great. Blackwelder has shown that the Ogden quartzite of Hague and Emmons does not exist as originally defined. Elsewhere in this report, it is shown that the Ute

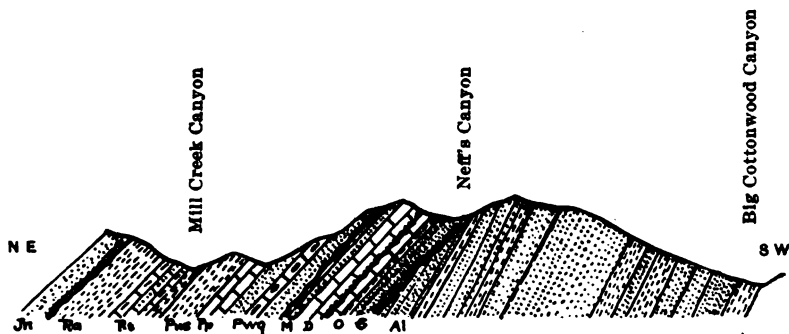


FIG. 2. SECTION EXPOSED BETWEEN THE MOUTH OF BIG COTTONWOOD AND THE HEAD OF MILL CREEK CANYONS

Al = Algonkian. C = Cambrian. O = Ordovician. D = Devonian. M = Mississippian. Pwq = Penn. Weber quartzite. Pp = Penn. Park City formation. Pws = Permian Woodside shale. Tt = Triassic Thaynes formation. Ta = Triassic Ankareh shale. Jn = Jurassic Nugget sandstone.

limestone of supposed Silurian age also has no existence as such in the central Wasatch, but is in reality the lower part of the Wasatch limestone reported as belonging to the Carboniferous. It seems strange that this relation should not have been discovered by the early workers on account of the marked contrast between the sequence of beds near Alta in Little Cottonwood Canyon and that seen across the divide to the north in Big Cottonwood Canyon.

BIG COTTONWOOD SECTION

At the mouth of Big Cottonwood Canyon is exposed the base of the great section of Paleozoic and Mesozoic rocks above referred to by King.

(dip N. 60°), the great canyon holds a general course N. 70° E. for nearly eight miles, slowly truncating the edges of the successively higher beds, which as we go east gradually change their strike toward the south. From its mouth for a distance of about six miles, the canyon is walled by brown and yellowish quartzites interspersed with thick beds of black and purplish blue slates. The upper six miles of the canyon show the post-Cambrian formations, the general continuity of the beds being seriously broken only at one point, opposite South Fork of Mill D. The top of the section passes beyond the northeast divide of the canyon into the northwest corner of the Park City district.

QUARTZITE-SLATE SERIES

The great quartzite and slate series is succeeded below by gneiss and schist or granite. The igneous nature of the granite contact was not recognized by the Fortieth Parallel geologists, who mapped the granite as Archean and described the contact as one of sedimentary unconformity. The quartzite succession was assigned to the Cambrian, including the lowermost exposures. In describing the rocks referred to the Cambrian in his recapitulation of the Paleozoic, King⁷ says:

"Thus far among the reported occurrences of the rocks of this horizon in the Cordilleras, the locality at the mouth of Big Cottonwood Canyon must remain as the finest example and the stratigraphical type. The lowest member—the Cottonwood slates, a group about 800 feet thick, which here rests upon highly metamorphic Archean schists—has thus far yielded no organic forms. The rocks are dark blue, dark purple, dark olive green and blackish argillites, all highly silicious and as a group sharply defined from the light-colored quartzite schists which conformably overlie them. This second group, by far the greatest of the whole Cambrian series, is a continuous zone of schists which have a prevailing quartzite character, though varied with considerable amounts of argillaceous matter. From 8000 to 9000 feet thick, it has a general uniformity of lithologic condition from bottom to top. . . . The prevailing colors of this member are gray, greenish gray, drab and pale brown, never dark colors. Conformably overlying it are 2500 to 3000 feet of cream and salmon color and white quartzites and quartzofelsites. Occasional sheets of conglomerate are seen in the quartzites not far below the summit of the Cambrian."

A few years later, in the course of his studies of the Cambrian sections of the Cordilleras, Dr. C. D. Walcott⁸ visited Big Cottonwood Canyon, examining the quartzite series in more detail and re-measuring the sec-

tion. Walcott's section⁹ is inverted, as originally published, and is here given in the natural order, as follows:

Big Cottonwood Section

	Feet
14. Superformation: Mixed sandy and calcareous rocks which rest conformably on 13 of the section and carry a fauna which refers it to the lower Silurian (Ord).	
13. Hard, silico-argillaceous shales, a little sandy in places.....	250
Fossils: At the base, <i>Cruziana</i> sp. associated with <i>Olenellus gilberti</i> ; 100 feet higher up, a band of shale afforded <i>Linguella ella</i> , <i>Kutorgina panula</i> , <i>Hyolithes billingsi</i> , <i>Leperditia argenta</i> , <i>Ptychoparia quadrans</i> and <i>Bathyuriscus producta</i> .	
12. Gray compact quartzitic sandstone.....	3,000
11. Purplish and reddish brown quartzitic sandstone.....	75
10. Gray compact quartzitic sandstone.....	700
9. Black, sandy, arenaceous, slightly micaceous shale.....	75
8. Light gray quartzite and quartzitic sandstone, in layers varying from 10 feet to 2 inches, the thin layers occurring as partings between the more massive bands of layers. In some places, the quartzitic sandstones show grains, and in others they are lost. Stains of purple, iron rust, reddish brown and buff color occur.....	2,700
7. Arenaceous and argillaceous slates, black, bluish black, drab and yellowish green. The exposure is extensive, the opportunity for finding fossils excellent, and the slates afford a beautiful matrix for their preservation, but none were observed.....	700
6. Light gray quartzite and quartzitic sandstone, in layers varying from 10 feet to 2 inches. In some places, the quartzitic sandstones show grains, and in others they are lost. Stains of purple, iron rust, reddish brown and buff color occur.....	200
5. Hard, black, arenaceous shale, with specks of mica on the surfaces. Quartzite and shale intercalated near the base.....	1,000
4. Light gray quartzite and quartzitic sandstone in layers, varying from 10 feet to 2 inches. In some places, the quartzitic sandstones show grains, and in others they are lost. Stains of purple, iron rust, reddish brown and buff color occur.....	700
3. Purplish, thin bedded sandstone, with bands of greenish yellow argillaceous shale near the summit.....	700
2. Massive bedded light gray quartzite.....	1,000
1. Black arenaceous shale, showing mud-markings and mud cracks, ripple marks.....	900
Total.....	12,000

Age of Series

From the occurrence of the *Olenellus* fauna in the shale member at the top of the series and the apparent conformity of the entire succession of

⁹ The section is given here as corrected by Dr. Walcott in his Correlation Papers, Bull. U. S. Geol. Surv. No. 81, p. 319. 1891.

quartzites and shales, Walcott was led to place the whole 12,000 feet of strata in the Lower Cambrian. The Fortieth Parallel geologists, reasoning that the granite at the base was pre-Cambrian in age and separated from the quartzite series by a great unconformity, also assigned it to the Cambrian period. It is significant that the description given by King of the upper part of the section includes sheets of conglomerate, which, however, Walcott does not mention. These occur in a succession of coarse sandstones, the individual pebbles being small, usually less than half an inch in diameter. Blackwelder¹⁰ has called attention to the strong lithological resemblance of these pebbles to the bright colored quartzites farther down in the series. He has also pointed out the fact that the section which is here 12,000 feet thick is much thinner to the north and that it is subject to rapid variations of thickness within short distances. These facts are taken to suggest the existence of an unconformity within the quartzitic series. At a horizon roughly estimated to be 1500 feet below the top of the quartzite in Big Cottonwood, Blackwelder reports the existence of a well-marked basal conglomerate, which he represents as lying upon the truncated edges of the lower members, showing, however, little angular discordance between the two sets of beds. This old erosion surface is taken as the base of the Lower Cambrian, marking the separation of the Cambrian from the Algonkian.

At the head of South Fork, near the Rexall mine, the writer found a heavy conglomerate composed of large, well-rounded quartzite and gneiss boulders lying upon a very black rock of strange characteristics, the description of which will be given later. Overlying the conglomerate are 700 feet of well-bedded white quartzite, showing several sheets of fine conglomeratic material. Above this quartzite is a shale 125 feet thick, and superjacent to this comes the lowest limestone series. Tracing the conglomerate northward, the underlying black formation gradually thins out and the conglomerate comes to rest on the next lower bed of white quartzite. Passing west of Kessler's Peak, this contact travels down the east face of Mineral Fork and crosses Big Cottonwood Canyon, where Blackwelder saw it, a short distance below the Maxfield mine. Maintaining a fairly constant distance below the top of the series, the contact rises rapidly on the north wall of Big Cottonwood Canyon and crosses the

be traced southward through the Alta basin at the head of Little Cottonwood Canyon, into American Fork Canyon.^{10a} At Santaquin, near the Union Chief mine 40 miles to the south, it is seen again, being there 600 feet below the top of the series. The black formation on which it rests at the head of Little Cottonwood Canyon seems to be absent everywhere within a few miles to the north and south of that place, not appearing in Big Cottonwood Canyon, nor at Santaquin to the south. From its occurrence thus traced for about 50 miles, it may safely be taken to be of wide distribution. That it truncates the lower beds, producing extraordinary differences in their thickness within short distances, is also clear from the rapid disappearance of the black member, above referred to, and from the fact that northward at Willard, Utah, the conglomerate rests directly on Archean gneiss. The possibility of original inequality of thickness must be taken into account in connection with the thinning of the lower series. The uniform thickness and wide distribution of the quartzite and shale member overlying this dividing plane, taken together with the great variation in thickness of the lower series, seem to imply the widespread truncation of the lower beds and their reduction practically to a peneplain before the upper beds were deposited. The complete removal of the great quartzite series over considerable areas must have required much time. A great gap therefore separates the Lower Cambrian quartzite at the top of the series from the great quartzite and shale series underlying it, and the two must be of distinctly different ages.

Accepting Walcott's fossil evidence of the presence of Lower Cambrian strata above the unconformity, it seems only proper to regard the quartzite-slate series below as of pre-Cambrian, and probably Algonkian age. It would then correspond to the Belt series of Montana and the Grand Canyon series of Arizona, in both of which the Cambrian strata are separated from the pre-Cambrian formations by similar unconformities.

A very different view is held by Daly and others, namely, that the oldest Cambrian fossils in the Rocky Mountains are Middle Cambrian and that the Brigham quartzite is of that age. The unconformity is regarded as representing only a brief time interval, and the great quartzite-slate series is made early Cambrian and not Algonkian in age. This view seems to call into question the faunal evidence upon which the presence of Lower Cambrian strata at the top of the series is based. Dr. Walcott very kindly supplied the writer with photographs of two specimens of *Olenellus gilberti*, which he found at the base of the shale bed, and there seems to be no reason to doubt their correct identification. A diligent search in all

^{10a}. See Plate I, fig. B.

the shale beds by the writer was not rewarded by the discovery of Cambrian fossils within the Cottonwood district. At Ophir, in the Oquirrh Mountains, and at Santaquin, the Middle Cambrian fauna which Dr. Walcott found 100 feet above the *Olenellus* fauna in Big Cottonwood Canyon are also found, and at least in one place at Ophir in the same relation to the Lower Cambrian fossil horizon. A later search at Santaquin may reveal the *Olenellus* fauna there.

If we accept *Olenellus gilberti* as the index fossil of the Lower Cambrian, then it seems that Daly must be mistaken in the statement that that

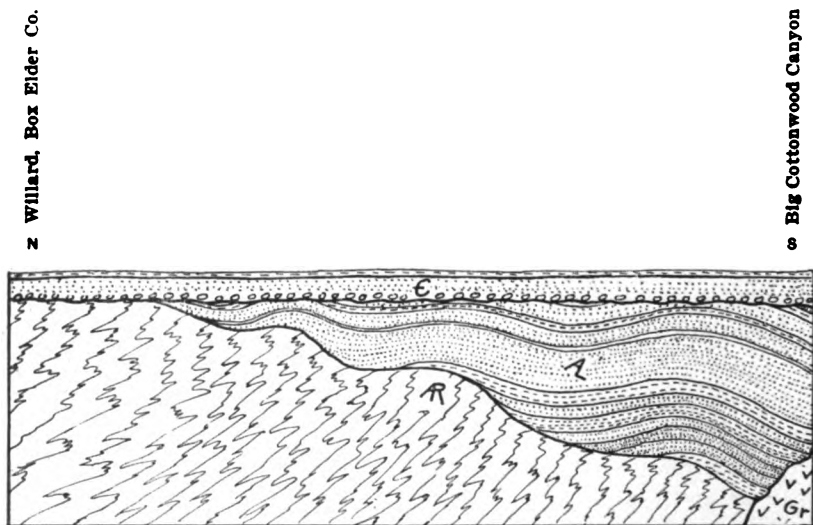


FIG. 3. SECTION FROM BIG COTTONWOOD CANYON NORTHWARD TO WILLARD, BOX ELDER CO., UTAH

Relation of the Algonkian (AL) slate and quartzite series to the Archean (AR) gneiss and schist, and the Cambrian (C) quartzite and shale

horizon is not represented by the Brigham quartzite and part of the overlying shale. That the shale beds of the great quartzite series below the unconformity have yielded no fossils after careful searching by many workers seems to argue against their Cambrian age. It is conceded by everyone who has seen them that the shales are well enough preserved to show good fossils, if any had been imbedded in them. There is, of course,

The variation of thickness of the Algonkian rocks might be accounted for in still another way. If they were laid down upon an irregular surface, filling up the valleys and thus reducing the relief, the surface upon which the Cambrian beds were laid down later might be relatively smooth and their uniform thickness would be accounted for, as well as the changeable thickness of the lower formations, but the relation of the beds above the unconformity to those below would be different. There would have to be practically no truncation of the lower members; the relation would be more nearly that of a disconformity, and the separation of the two series would be much more difficult on account of the lack of discordance. The advancing Lower Cambrian sea would rework the surface materials and a gradual transition would be established. Moreover, the close resemblance of the large rounded quartzitic boulders in the conglomerate to the underlying quartzites is strong evidence that they were derived from them by stream erosion. This implies that the lower series was consolidated into hard sandstones before the invasion of the Cambrian sea, an inference which points to the much greater age of the lower quartzites. It seems, therefore, only possible to account for the great variation in thickness of the Algonkian rocks by erosion, before the deposition of the Lower Cambrian sediments upon their bevelled edges.

Relation of Algonkian to Archean

The relation of the Archean rocks to the Algonkian is not shown in the Cottonwood region. The base of the Algonkian series is not exposed. From its relation elsewhere, an unconformity doubtless exists and has been represented in the figure above given. The Archean oldland may have been devoid of relief but probably had some low monadnocks in places. If the Algonkian rocks are continental in origin, as is generally believed, the surface upon which they were deposited must have been relatively low and flat. The spreading fans and deltas of the Algonkian rivers slowly extended themselves and covered the surface of the Archean rocks. An unconformity, then, with overlap away from the source of supply, must separate these pre-Cambrian formations from the underlying Archean.

The highest member of the Algonkian in the Cottonwood region is a rock of somewhat unique characteristics. It is exposed at the head of South Fork and may be traced south into American Fork Canyon but soon disappears by overlap of the Cambrian beds. It has not been found in any other part of the range, but upon one of the islands of Great Salt Lake a rock of similar occurrence is found. The peculiar nature of the

deposit consists of the extraordinary distribution of large and small boulders within a rock which is otherwise fine enough to be classed as a shale or very fine sandstone. The unusual occurrence of the scattered boulders of different sizes calls for a special explanation. Dr. Fred J. Pack¹¹ of the University of Utah has suggested a glacial origin for the boulders that occur in a similar fine-grained black rock on Stansbury Island in Great Salt Lake. At that place, they show facetting suggesting ice erosion, though glacial striae have not been seen. In the Cottonwood deposit, the boulders are of greatly varying sizes, from small pebbles to blocks weighing several tons. The smaller ones show water action in that they are much rounded, but the extremely large ones are distinctly angular. It is difficult to imagine how such masses came to be imbedded in a rock which is otherwise so uniformly fine grained, unless we appeal to an agent like ice which has the power to carry them long distances and deposit them without changing their form to any marked extent. Ice-rafting might be suggested as a possible means for their irregular distribution. Facetting and more or less complete rounding of the smaller pebbles would also be conceivable on such an hypothesis. In fact, the heterogeneous nature of the deposit is one of the strong factors in support of the supposed glacial origin (see Plate II).

In the March number of the *American Journal of Science* for 1907, Coleman,¹² after a brief review of the reported occurrence of Paleozoic ice ages in many parts of the world, suggests the probable existence of a Lower Huronian ice age:

"For several years, it has seemed to me very probable that there was a still more ancient ice age, at the beginning of the Lower Huronian in the Archean as defined in Canada or the Archeozoic or lowest Algonkian as defined by various American geologists. The so-called Huronian 'slate conglomerate' of Ontario has attracted attention ever since Logan and Murray mapped and described it in the typical region north of Lake Huron nearly fifty years ago. Good descriptions of it are given by Logan in the 1863 report of the Canadian Geological Survey; where he refers to the different kinds of rock inclosed as pebbles or boulders, granite, felsite, certain green-stones and jaspers, for example; and describes the matrix as sometimes slaty, sometimes more quartzitic or like diorite or green-stone. At present the matrix would be called gray-wacke or slate though sometimes it is schistose or looks like an eruptive rock.

"The pebbles are in many cases subangular or sharply angular and are found miles away from any known source; and as they may be of any size up to blocks weighing tons, and are frequently very sparsely scattered through an unstratified matrix, a stone or two in several yards, one cannot help suspecting that the transporting agency was ice rather than water."

¹¹ Personal communication.

¹² A. P. COLEMAN: "A Lower Huronian Ice Age," *Am. Jour. Sci.*, Vol. 23, p. 187. 1907.

Coleman sums up the evidence for a Lower Huronian ice age as follows:

"A peculiar rock consisting of graywacke or finer material showing little or no stratification but containing pebbles or stones sometimes crowded but more often scattered a few feet apart, is found from point to point over an area 800 miles long by 250 miles broad. The stones are of all sizes up to diameters of several feet and of all shapes from rounded to angular, many being subangular with rounded corners. The stones are of several different kinds, some fragments of immediately underlying rock, others having a distant source.

"In the Cobalt region a few polished and striated stones have been broken out of the matrix. They are closely like the Pleistocene boulder clay of the same region except that they lack the Niagara limestones of the recent drift.

"Hand specimens of matrix and enclosed pebbles are precisely like the Dwyka tillite or conglomerate of South Africa which is undoubtedly of glacial origin."

It is obviously impossible to connect these deposits in eastern Canada with those of the Cottonwood area in Wasatch Mountains, without some surer means of correlation than lithological similarity. If, however, we accept Coleman's evidence, the occurrence of glaciation is probable over an area which is much too large to be attributed to local mountain glaciers. The two Utah occurrences are 60 miles apart and were undoubtedly of much wider distribution, having been removed by erosion previous to the deposition of the Cambrian beds, as previously explained. It is highly probable that these exceptional sediments are to be explained on the same basis, and that suggested by Coleman deserves serious attention and may be accepted at least for the present. An ice age of sufficient duration to manifest itself over such a large area in eastern Canada might easily be expected to register its effects in the western part of the same continent, especially at approximately the same latitude and northward.

Mr. E. L. Bruce, a member of the Canadian Geological Survey who has seen the rocks as they occur in Canada and also the writer's material, says that they are strikingly similar in almost every detail. The description quoted above from Coleman's article applies equally well to the black rock at the head of South Fork in Big Cottonwood Canyon. If we accept them as glacial deposits, they are probably of the same age, and the quartzite-slate series in the Wasatch and Uinta mountains is much older than has been thought up to the present time. From the obvious scientific importance of establishing the existence of an ice age in that early period of the earth's history, the question deserves further careful study.

Origin and Nature of the Algonkian Sediments

The nature of the Algonkian rocks has already been partly discussed and a very general description given in the sections by the Fortieth Parallel geologists and Dr. Walcott. These may be briefly summarized as follows: The prevailing rocks are quartzites and interbedded shales, the quartzites being mostly light colored, white and yellow to light brown; the shales, dark purple and green to black. Toward the top of the series, thin sheets of conglomerate occur in the quartzites, in which small well-rounded pebbles of quartz and quartzite are abundant. In a dark shale at the base of the series, mud cracks are abundant. To these characters may be added several others observed by the writer and also mentioned by Blackwelder. The quartzites are often prominently cross-bedded, the discordant angularity of the beds being usually of small amplitude. Ripple marks of the long parallel type are often common in the sandy shales. Limestones are totally absent, and though conditions favorable to the preservation of fossils seem to be abundant and right, no organic remains have been discovered.

From the intermediate geographical location of the Big Cottonwood section with respect to the Grand Canyon section on the south and the many occurrences of thick pre-Cambrian sediments to the north in Idaho and Montana, and from the fact that many of the above mentioned features of the Wasatch Algonkian have also been recorded from these other localities, it seems logical to suppose that they must have the same or a very similar origin. Upon whatever basis one is explained, the rest will probably also be explicable. Limestones and dolomites are met with in the northern and southern series and show that those regions had more varied conditions of sedimentation, involving periodic inundations of the sea, unless they are of fresh water origin. The major portions of the rocks are, however, clastic sediments and show physical characteristics which point to a continental origin. Shrinkage cracks and ripple marks in the shales and shaly sandstones indicate extensive mud flats comparable to the flood plains of many of our large rivers. Cross-bedding of the type here found suggests shifting water currents such as those of terrestrial rivers rather than wind. So that if we postulate a river origin for most of the quartzites and shales, we have at once a complete explanation of

formations. Subaërial deposition in an arid region would also account for the highly oxidized character of most of the beds. While a final conclusion must be reserved for future more extended studies, the presumption from the facts at hand is in favor of a continental origin for all of the Wasatch Algonkian and a large part of the Arizona, Idaho and Montana occurrences.

We may now inquire into the probable situation of the Archean oldland from which these sediments were derived. It is clear from the general distribution of the Algonkian rocks above referred to in a north-south belt from Arizona, through Utah, Idaho and Montana into British Columbia, that the source must have been to the east or west. If we examine the sections to the eastward, we find that as we approach the north-south line of the Front Range, these pre-Cambrian quartzites thin away and disappear, and we have late Cambrian strata resting with unconformity upon Archean rocks. It appears then that here we have an area which was actively eroded during Proterozoic and most of Cambrian time and that did not become an area of deposition until late Cambrian time. From the general absence of Lower Cambrian formations in this region and their presence in the Wasatch Mountains and westward in Nevada, it is clear that the Cambrian sea came in from the west. This seems to indicate the absence of any considerable land mass to the west and reduces our source of supply to the eastern oldland. We may then consider the continental divide to be the Archean axis of the Front Range in Colorado and its northward extension into Canada, from which the rivers flowed to the east and to the west. Those draining the western slopes of this Archean elevation opened out upon lowlands in central and eastern Utah and to the north and south. Here subaërial deposition began in the formation of great fans spreading westward and becoming more or less confluent toward the north and the south.

CAMBRIAN STRATA

The base of the Cambrian strata is now drawn at the unconformity above described. The separation of the rocks from the much older Algonkian formations has reduced their thickness from 12,000 feet, as formerly estimated, to less than 1000 feet.

The lowest Cambrian formation is a conglomeratic quartzite 700 feet thick. No fossils have been found in it, and its age is fixed by its position above the well marked unconformity and below the succeeding shale bed carrying the *Olenellus* fauna. At the base lies a heavy conglomerate composed of rounded pebbles and boulders of quartzite and gneiss and the

black conglomerate already referred to as occurring at the head of South Fork. The conglomerate is nowhere of very great thickness, being usually less than 10 feet. Within the lower 200 feet of the succeeding quartzite are several sheets of fine conglomerate, the pebbles being quartz and quartzite. The remaining 500 feet are of coarse white quartzite which weathers to a light yellow or cream color. It is well bedded into layers varying from a few inches to several feet in thickness. Toward the top, the beds become uniformly thinner and gradually pass into shale, the latter being intercalated between the thin sheets of quartzite. Hanging from the under side of several quartzite layers in this transition zone are curious *Arthropycus*-like structures. The sandy shale layers show well-preserved ripple marks of the parallel types, proving the shallow water origin of these sediments and their transitional character.

A similar quartzite formation is of wide occurrence in the Wasatch Range to the north and south and in the Basin ranges to the west. It is everywhere very similar in its appearance and physical characteristics and is followed by a dark shale of Lower or Middle Cambrian age. From its occurrence near Brigham City, Utah, Walcott has called it the Brigham quartzite, and though it is better shown at Willard and several other places along the range, we may retain the original name to avoid repetition. In Big Cottonwood Canyon, it is well exposed just below the old Maxfield mine and may be seen on both walls of the canyon. Southward, it becomes the east wall of Mineral Fork, underlying the limestone and shale which form the capping of Kessler's Peak. Dipping to the northeast, it cuts across the head of South Fork and crosses the divide into Little Cottonwood Canyon just north of Alta.

Overlying the Brigham quartzite, just at the Maxfield mine, is a dark micaceous, sandy shale, which, from its prominence just at the little town of Alta, we may call the Alta shale. It rests conformably on the Brigham quartzite with which it is in bold contrast on account of its black color. It is somewhat variable in thickness, ranging from 150 to 200 feet. From a sandy character near the base, it passes slowly into a thinly bedded, fine-grained shale in the middle and upper part, representing a continuous depositional unit. From two horizons within the Alta shale, 100 feet apart, Walcott¹⁴ reports the following Middle and Lower Cambrian fauna from Big Cottonwood Canyon:

¹⁴ C. D. WALCOTT: U. S. Geol. Surv. Bull. No. 81, p. 319. 1891.

Middle Cambrian.....	{	<i>Lingulella ella</i>
		<i>Kutorgina pannula</i>
		<i>Hyolithes bilingui</i>
		<i>Leperditia argenta</i>
		<i>Ptychoparia quadrans</i>
		<i>Bathyriscus producta</i>
Lower Cambrian.....	{	<i>Olenellus gilberti</i>
		<i>Cruziana</i> sp.

Dr. Walcott continues: "As in the Eureka and Highland Range sections, the *Olenellus* zone is confined to a very narrow belt just above the quartzite. The silico-argillaceous shales (Alta) above occupy the position of the 4650 feet of Prospect Mountain limestone and Secret Canyon shale of the Eureka section. The Hamburg limestone and Hamburg (Dunderburg) shale of the latter are absent in the Big Cottonwood section, causing an unconformity by non-deposition. The section in the Oquirrh range above Ophir City has a quartzite at the base with shales above it carrying *Lingulella ella*, *Olenellus gilberti* and *Bathyriscus productus*, as determined by the collections brought in by the Wheeler survey. It is probable, however, that as in the case of the Big Cottonwood section, *Olenellus gilberti* occurs at the base of the shale, and the other two species at a higher horizon."

From this, it appears that the Middle Cambrian is only represented by the middle and upper part of the Alta shale, and the Upper Cambrian is wanting altogether. There exists, therefore, within the shale a disconformity between the Lower and Middle Cambrian strata and at the top a great hiatus representing the entire Upper Cambrian series.

ORDOVICIAN STRATA

Disconformably overlying the Alta shale is a limestone and shale series of which the following section, measured at the south end of the Reade and Benson ridge at the head of South Fork, is typical:

Section in South Fork		Feet
13. Alternating blue shale and limestone conglomerate in beds 1-6 inches thick.....		10
12. Alternating shale and limestone, passing into shale.....		20
11. Thin fissile blue shale.....		6
10. Dark blue thin-bedded limestones, partings exceedingly irregular....		55
9. Dark blue heavy bedded limestone with a wormy appearance, holes far apart.....		45
8. White limestone, thin bedded.....		10

	Feet
7. Dark blue wormy looking limestone greatly resembling typical bird's-eye limestone of the east.....	85
6. Thin-bedded brown shale, strongly jointed toward the top.....	60
5. Finely intercalated lime and shale.....	10
4. Light blue streaky limestone, weathers white.....	15
3. Blue heavy bedded limestone with wormy appearance toward top....	60
2. Brown shale, blocky appearance from extreme jointing.....	75
1. Blue limestone intercalated with seams of clay giving a banded appearance.....	30
Total.....	481
Subformation: Alta shale.....	200

No fossils were found in the beds of the above section, but the ramifying tubes in the "wormy" looking members are very suggestive of some form of life. Placed side by side, it is difficult to detect any appreciable difference between the specimens of the Ordovician Bird's-eye (Lowville) limestone of New York and those taken from this section. Within this part of the Wasatch, this character is a constant one and is a striking feature by which the rocks of this horizon can always be told. Though it has afforded no fossils within the area studied, it is interesting as representing the first limestone making period of this region. No coarse clastics occur, and the series belongs essentially to the off-shore facies, where conditions of sedimentation were constant for considerable lengths of time, but on the whole subject to quite frequent change. The period is brought to a close by a withdrawal of the sea and exposure of the surface to erosion. The limestones of this new land area were broken up and worn round, typically lens-shaped, and deposited in a curious helter-skelter fashion with many of the flat pebbles standing on edge. Hand specimens taken are almost identical in appearance with those described and illustrated by Blackwelder¹⁵ from China. Intra-formational conglomerates from the Lower Ordovician have also been reported from Pennsylvania.¹⁶ In the Lakeside Mountains, west of Great Salt Lake, there is a bed of similar limestone conglomerate of considerable thickness belonging to the Beekmantown horizon. While the age of the beds below the "edgewise" conglomerate of the above section cannot be told definitely because no fossils were found in them, they are referred provisionally to the Ordovician. They are of special interest because the largest ore deposits of the region have been found in them. The rich galena bedded vein of the Maxfield

¹⁵ E. BLACKWELDER: *Research in China*, Vol. 1, Part 2, pp. 384-390.

¹⁶ G. W. STOSE: *U. S. Geol. Surv. Folio 170*. 1910.

T. C. BROWN: "Notes on the Origin of Certain Paleozoic Sediments," etc., *Jour. of Geol.*, Vol. XXI, pp. 232-250. 1913.

property at Argenta, in Big Cottonwood Canyon, is a good example, and from this occurrence the name Maxfield formation is suggested for the series.

SILURIAN STRATA

The presence of Silurian strata in western America was doubted for a long time. It has recently been shown by Kindle,¹⁷ however, that the Silurian period is represented in a number of widely separated regions, and among them, in the northern Wasatch. In Green and Logan Canyons, east of Cache Valley, Cache County, Utah, Kindle reports the following fauna obtained by F. B. Weeks:

Favosites gothlandica Lamark
Favosites niagarensis Hall
Halysites catenulatus Linn.
Zaphrentis sp.
Pentamerus oblongus Sow.

Below the Paradise limestone which carries these forms, there is a dark colored limestone of undetermined age. Above it there is a dark magnesian limestone 800 to 1000 feet thick, carrying Devonian types. How far the Silurian strata extend toward the south is not known. Blackwelder reports limestones 1000 to 1500 feet thick in the northern Wasatch, on the west side of Cache Valley, which lie between the Geneva formation of Ordovician age and the identifiable part of the Mississippian. In the lower part of this limestone series occur *Halysites* and *Favosites*, and a brachiopod fauna somewhat higher up is thought by Kindle to be the same as his *Pentamerus* fauna of the Bear River range.

From the occurrence of these limestones at Ute Peak, near the southern end of Cache Valley, the Fortieth Parallel geologists gave the name Ute limestone to the Silurian strata of the Wasatch region. Special mention was made of the occurrence of this member at Alta, in Little Cottonwood Canyon, where a limestone 1000 feet thick is boldly exposed above the Cambrian shale on the north side of the canyon. Above this so-called Ute limestone, and separating it from the higher limestone series known as the Wasatch limestone, are nearly a thousand feet of quartzite and shale, mostly quartzite, which were called Ogden quartzite from their somewhat greater development in Ogden Canyon. The Ute limestone thus appears as a stratigraphic unit between two well-defined quartzite formations in its typical occurrence. In the latter part of this report, it

¹⁷ E. M. KINDLE: "Silurian Fauna in Western America." Am. Jour. Sci., 4th Ser., Vol. 25. 1908.

is shown that the so-called Ogden quartzite is an overthrust block of partly Algonkian and Cambrian quartzite and shale, lying upon limestone of Devonian age. Blackwelder has recently shown that the same relation exists in Ogden Canyon and that the Ogden quartzite does not exist as originally defined. It now appears that the typical Ute limestone also has no existence as a regular depositional unit but is in reality the lower part of what was called the Wasatch limestone. The name Ute limestone, therefore, must go the way of the Ogden quartzite and be discarded. The Fortieth Parallel section is thus reduced over 3000 feet in thickness by the elimination of these two members. No name has yet come into general use for the Silurian strata of the northern Wasatch as they have been little studied, but the one employed by Blackwelder, viz., Paradise limestone, might serve. In the central Wasatch, this is apparently wanting altogether.

The absence of Silurian strata in the central Wasatch may be due to non-deposition or to their complete removal by erosion. The only evidence of a great erosion interval in this part of the section is that already mentioned at the top of the Maxfield formation. Limestone conglomerates, however, are looked upon with suspicion as forming true basal beds since the discovery of the intra-formational types. Nevertheless, there is no reason why this could not be a basal conglomerate upon an old erosion surface, for limestones of Lower Ordovician age are of wide distribution in the west.

DEVONIAN STRATA

Below the lowest *Productus* horizon of the Mississippian in the Cottonwood region occurs a cherty limestone in which there are abundant corals of a few species. Fossils apparently from this horizon were reported by Professor Sanborn Tenny¹⁸ of Williams College as early as 1873. He described the locality as follows:

"In a position southeast of Great Salt Lake City on the divide between Great Cottonwood and Little Cottonwood, 9,000 feet to 10,000 feet above sea, is a dark blue limestone, containing corals."

The corals collected were two species of *Zaphrentis* and one of *Syringopora*, which R. P. Whitfield called *Syringopora maclurei* Billings but regarded as probably a new species. These were roughly referred to the

Tenny, for Devonian strata have generally been held to be absent in this part of the range. Boutwell,¹⁹ in his report on the Park City district, says that Devonian fossils have only been found in the northern part of the Wasatch range, and the formation in which they occur has been withdrawn from the Wasatch limestone and correlated with the Jefferson limestone.

Section in South Fork

(Upper continuation of the section given under the Ordovician)

Pennsylvanian (Weber quartzite) :		Feet
30. Hard brownish sandstone.....		500
29. Limestone conglomerate.....		3 to 10
Unconformity.		
Mississippian (Reade formation) :		
28. Cherty light yellow argillaceous limestone with large Zaphrentis corals.....		5
27. Thin-bedded fossiliferous blue limestone.....		350
26. Brown and red shales.....		35
25. Cream colored sandstone.....		250
24. Massive blue limestone with productus.....		300
Devonian (Benson limestone) :		
23. Hard dark blue cherty coralline limestone.....		100
22. Massive dark blue limestone.....		300
21. Fossiliferous blue limestone.....		3
20. Thick-bedded blue limestone.....		100
19. Dark blue cherty and brecciated limestone.....		200
18. Hard blue limestone.....		100
17. Dark porous limestone, very fossiliferous.....		21
16. Thick-bedded blue limestone, extensively bored.....		120
15. Thick-bedded light blue limestone.....		43
14. Thin-bedded blue limestone.....		45
Total.....		2,475
Disconformity.		
Subformation : <i>Marfield formation.</i>		

Kindle²⁰ has described the Jefferson limestone fauna and traced the beds from their type locality in Montana southward into the Wasatch Mountains of northern Utah. The following section is given from Green Canyon :²¹

Section in Green Canyon

	Feet
D. Gray non-magnesian limestone, partly covered.....	900±
C. Dark gray to black magnesian limestone, generally with saccharoidal texture.....	1,100±
B. Thin-bedded limestone, buff or brownish near the top, with peculiar concretionary development with thin-bedded bluish-gray limestone in lower part.....	100
A. White to light gray magnesian limestone, with chert or siliceous beds locally developed.....	150
Total.....	2,250

Kindle correlates the dark magnesian limestone (C) with the Jefferson limestone of Montana. The following is a list of the species obtained from Green Canyon:

Productella spinullicosta
Camarotæchia sp.
Spirifer argentarius
Leiorhynchus utahensis sp. nov.
Spirifer disjunctus var. *antimasensis*
Pterinopecten sp.
Actinopteria sp.
Cytherella sp.

In discussing the evidence of the fauna of the Jefferson limestone, Kindle has chosen three forms, *Spirifer utahensis*, *S. engelmanni* and *Martinia maia*, as the most abundant species represented, all of which are not reported from the northern Wasatch section. All of these, however, and seven other types common to the Jefferson are characteristic fossils of the Nevada limestone of Eureka, Nevada, with which it is correlated.

The Jefferson limestone has a known north-south extent of 425 miles, and from the thickness given for it in the northern Wasatch, it should be expected to continue southward a considerable distance. Aside from strata of close lithologic resemblance with the Jefferson reported by Blackwelder from the region northeast of Ogden, nothing is known of these beds south of Cache Valley. Eastward, they are not known beyond a line through central Montana and western Wyoming. From northern Colorado south to the southern part of New Mexico, the Ouray type of Devonian prevails, characterized by *Camarotæchia endlichi* and other Upper Devonian types. The east-west line which separates these two faunas appears to be the borderline between Colorado and Wyoming, latitude 41° N. Extended westward, this line intersects the Wasatch

about midway between Ogden and Salt Lake City and includes the Eureka district of Nevada in the southern division. Since, however, the Nevada limestone fauna shows close affinity with the Jefferson rather than the Ouray, the line which separates the latter from the Jefferson and Nevada limestone faunas must curve to the south somewhere in Utah. It should be expected that these two distinct faunas representing different parts of the Devonian, the Jefferson, Lower and Middle, and the Ouray, Upper, will overlap somewhat, but thus far no section has been found where this condition is shown.

Ouray Type of Devonian in the Central Wasatch

It was with very great interest that the writer discovered *Camarotæchia endlichi* and a number of other typical Devonian forms in the Cottonwood region. On Montreal Hill, near the head of Mill D, South Fork, in Big Cottonwood Canyon, occur very fossiliferous light blue limestones, at the base of which the following forms were obtained:

Schuchertella chemungensis Hall
Orthoceras sp.
Spirifer orestes var. *wasatchensis* var. nov.
Spirifer sp.
Fenestella sp.
Rhynchonella sp.

Immediately overlying this horizon and ranging through about 250 feet of limestones occur the following forms:

Euomphalus utahensis Hall and Whitfield
E. latus White
E. ophirensis H. and W.
Spirifer orestes var. *wasatchensis*

In a third richly fossiliferous horizon, in which *Spirifer orestes* var. *wasatchensis* and *Eunella linklani* are the most abundant, practically making up the body of the limestone, occur the following:

Spirifer orestes var. *wasatchensis*
Eunella linklani Hall
Cystodyctia gilberti Meek
Euomphalus cf. *cyclostomus*
Athyris coloradensis Glrty, cf. *A. brittsi* Miller
Aviculopecten sp.
Camarotæchia sp.

In an outcrop considerably higher up, stratigraphically, but almost completely covered so that it was somewhat doubtfully in place, two specimens of the following well-known Ouray limestone type were obtained:

Camarotoechia endlichi Meek

Of the above species, the ones having the widest range are *Euomphalus* and *Spirifer orestes* var. *wasatchensis*. *Euomphalus utahensis*, *E. larus* and *E. ophirensis* have commonly been described as Mississippian from their resemblance to the Waverlyan species of the Mississippi Valley. Their association here with a Devonian fauna, and their range practically from the bottom to the top, indicates that they are probably older than Mississippian, though they may have persisted in other sections into the lower part of the Mississippian. It would otherwise be necessary to assume that the Devonian forms had survived till the Mississippian in order to explain this association, but this seems hardly warranted from the occurrence of *Eunella linkleri* Hall and *Cystodyctia gilberti* Meek which are described elsewhere as coming from the Middle Devonian (Lower Hamilton of Ohio).

In looking for the equivalent of this fauna in the West, that of the Ouray limestone in western Colorado suggests itself both from its proximity and its striking faunal resemblance. Kindle,²² who has described the Ouray fauna and has done more than anyone else in suggesting a correlation of the western Devonian strata, has the following to say:

"*Camarotoechia endlichi* may be considered the most characteristic species of the Ouray fauna, for it has been found at practically every outcrop where the fauna has been recognized from northern Colorado to southern New Mexico."

The occurrence of this widespread species in the central Wasatch has brought the western border line of the Ouray fauna nearly 200 miles west of the western boundary of Colorado, which Kindle believed to mark its western limit. While the outcrop from which the Wasatch representatives were obtained was poorly exposed and their associates were not discovered, they may nevertheless be present in the Wasatch region, and later search should reveal them. The presence, however, of this most characteristic species is, it would seem, sufficient to indicate the equivalency of the two formations. Moreover, the resemblance of the faunas that were found below the *endlichi* horizon to the Upper Devonian

The stratigraphic relations of these beds to the underlying non-fossiliferous limestones provisionally assigned to the Ordovician is one of disconformity. The beginning of Devonian sedimentation is very clearly marked by a limestone conglomerate which rests upon a thin bed of yellowish-green shale, which in turn rests on a thick limestone member. This condition is best shown on the Reade and Benson ridge, just above the old mine workings of the same name. It is also exposed on the ridge between Day's Fork and Little Cottonwood Canyon, just west of Flagstaff Mountain. No angular discord between the beds above and below the break could be detected, though the presence of the hiatus is physically indicated by the unmistakable conglomerate.

Upward, the Devonian strata seem to be continuous with the succeeding Waverlyan limestones. In this respect again, the central Wasatch is like the Colorado and New Mexico areas where deposition is thought to have proceeded continuously from the Upper Devonian into the Mississippian. From the occurrence of these limestone beds on the Reade and Benson ridge, the name Benson limestone is proposed to designate the part belonging to the Devonian. They range as above stated from Middle to Upper Devonian and are succeeded by Lower Mississippian limestones without any observed disconformity.

MISSISSIPPIAN STRATA

Rocks of Carboniferous age have been known from the Wasatch Mountains and the Great Basin region since the first explorations of Captain Stansbury in the early fifties. It was left, however, to the Fortieth Parallel geologists to give them a name and describe their stratigraphic relations, thickness and distribution. King applied the name Wasatch limestone to a succession of strata 7000 feet thick and composed mostly of limestones supposed to be of "sub-Carboniferous" age. Aside from the fact that this name was preoccupied for a Tertiary formation, it is now known that the original Wasatch consists of several stratigraphic members, ranging in age from Ordovician to Mississippian. In the northern Wasatch, the Paradise limestone of Silurian age and nearly a thousand feet of limestone identified by Kindle as the equivalent of the Jefferson have been separated from the lower part of the Wasatch. The rest has been regarded by Girty as Lower and Middle Mississippian, the lower division probably correlating with the Madison limestone. It seems advisable, therefore, to discontinue the use of the name Wasatch limestone as employed by King.

fauna, a middle sandstone and shale, apparently barren of fossils, and an upper limestone series which is very fossiliferous. These beds are well exposed in Big Cottonwood Canyon at the northern end of the Reade and Benson ridge which separates South Fork from Day's Fork. At Green's Hill in South Fork, the lower limestone can be traced across the canyon from east to west. From the cliff which rises on the west, the following forms were obtained:

Productus semireticulatus

Productus cora

Derbys sp.

Hapsyphyllum sp.

The sandstone and shale which overlie this limestone member were not well exposed within the district, usually forming the bottom of gulches because of their poorer resisting qualities to weathering and being largely covered with talus and soil. No fossils were found in them, but they may have been overlooked because of poor exposures. The sandstone, where seen, is composed of much angular material giving it the aspect of a breccia. The prevailing color of the sandstone is light yellow, straw color, while the shale which overlies it has a reddish tint. It is an interesting fact that Blackwelder has noted a similar occurrence sixty miles to the north, in Ogden Canyon, and several localities thereabouts. The exposures there are apparently better and have been carefully described. Lavender and maroon shales with abundant sun-cracks filled with mud and sand and the same brecciated appearance are noted. From these and other characters, a continental origin is suggested, the necessary conditions being found on the surface of deltas of flat gradient in regions which are either generally or seasonably arid. The presence of this non-marine member within the Mississippian was not noted until it was discovered in Ogden Canyon by Blackwelder²³ in 1910, and its recognition in Big Cottonwood Canyon by the writer gives it a much wider distribution and importance as a stratigraphic unit. It will, no doubt, partly account for the limited development of the Mississippian rocks in the Wasatch Mountains. In this connection, the unconformity at the top of the over-lying thin-bedded limestones is of great importance. As will be shown, this represents a great interval of time during which

Caninea cylindrica Scouler
Spirifer striatiformis Meek
Dielasma attenuatum Martin
Seminula subtilita
Spirifer rockymontanus
Productus semireticulatus
Phyllipsia cf. *trinucleata* Herrick
Amplexus sp.
Orbiculoidea newberryi
Spirifer sp. nov.

Caninea cylindrica is a well-known European species and so far as the writer is aware has not been recognized before in America. It is characteristic of the middle part of the Lower Carboniferous in Belgium and the region about Bristol, England. Probably next in importance is *Spirifer striatiformis* which is very abundant in the Cottonwood region. It likewise points to the Middle Mississippian.

By far, the most abundant form is the great coral *Caninea*. The individuals lie closely packed together in a layer about three feet thick, being very firmly cemented together with a siliceous clay which has become exceedingly hard. They were discovered by the writer in the early part of the season, and it was thought that they would make an easily recognizable reference horizon on account of their abundance and size, but while their general position was located in many places, no other occurrence was found.

Immediately overlying this coral bed is the basal Pennsylvanian conglomerate made up of rounded chert pebbles and silicified corals together with much fine material. This erosion surface truncates the lower beds, as may be inferred by the absence of the coral layer in all other places within the district except the one in which these interesting forms were first discovered near the mouth of South Fork. Careful observation seems to indicate some difference of dip between the upper quartzite beds and the lower limestones. The relation, therefore, is one of low angular unconformity.

Unconformity between the Mississippian and Pennsylvanian

There can be no doubt that there exists an unconformity at the top of the Mississippian in the Cottonwood section. The occurrence of a similar break farther to the north has also been reported by Blackwelder²⁴

a cavernous weathered surface of fossiliferous gray limestone. Just above the contact lies a coarse sandstone which consists of well-rounded frosted sand-grains bound in a deep red matrix and including bits of limestone and black chert from the underlying series. Although the bedding of the Morgan formation is essentially parallel to that of the limestone below, the relations here clearly indicate a disconformity, signifying an erosion epoch between the Mississippian and the Pennsylvanian." From faunas obtained above the disconformity, which show close relationships, the erosion interval is thought to be geologically brief in that region.

Dr. C. P. Berkey²⁸ has also described an unconformity at the base of the Weber quartzite in the western Uintas. He says in part:

"The base of the overlying formation, chiefly quartzite, is a true basal conglomerate. There are abundant fragments and pebbles and boulders from the cherty limestone bed immediately below, and in some places the finer cementing or filling matter is calcareous rock flour (calcilutite) and granular limestone (calcarenite) and chert (sillicarenite). Fossils are abundant below the break but rare above it in this area. From the above, it is certain that there is an erosion disconformity in the Upper Carboniferous of the Uintas that marks moderate readjustment of levels, so that the strata are not perfectly conformable in angle, although the later folding of the range has been so much more profound that this is lost sight of except along the immediate break."

In the western Uintas, there are two strongly developed quartzites. Barring discrepancies in thickness and noting only succession, the uppermost one of these would appear to correspond to the true "Weber." The erosion break occurs here at its base. While Berkey puts the disconformity into the Upper Carboniferous, he establishes the fact that it occurs below the Weber quartzite, which corresponds exactly with its position in the Big Cottonwood section. Many of the details of description also correspond, such as the prevalence of cherty pebbles and much fine material and slight discordance of dip between the upper and lower layers. An absence of fossils above the break in these two sections is also significant. In the northern Wasatch sections at the base of the Morgan formation, fossils occur in limestone layers, showing, according to Dr. Girty, that the unconformity there corresponds to a brief time interval. To decide the value of the unconformity, it is only necessary to

Mercur Section

In Lewiston Canyon, at the head of which is the little mining town of Mercur, there is exposed a great anticlinal fold, the axis of which runs northwest and southeast, somewhat diagonal to the general trend of the range, which is north-south. Lewiston Canyon cuts directly across the fold, exposing the anticline on both sides of the canyon. The lowest rocks brought up are of Lower Carboniferous age, and the highest exposed, directly over the axis of the fold, are also of that age. The crest of the range to the east rises on the east limb or flank of this anticline, and here are exposed the rocks of Upper Carboniferous age. The section thus exposed is as follows:

	Feet
4. Upper intercalated series.....	5,000-6,000
3. Great blue limestone.....	5,000
2. Lower intercalated series.....	600
1. Lower blue limestone.....	200

Above the Upper Intercalated series comes the great Weber quartzite 8000 feet thick exposed on the eastern slopes of the Oquirrh at Bingham and northward. Below the Lower Blue limestone, in Dry Canyon, which parallels Lewiston Canyon on the north, are several hundred feet of Lower Carboniferous limestone, below which come 2000 feet of Devonian, Silurian, Ordovician and Cambrian strata. There is thus a great series of sediment exposed in these three localities ranging from the Cambrian to the Upper Carboniferous.

Fossils obtained from the Lower Blue limestone by Mr. Spurr,²⁶ and examined by Professor Schuchert, were found to be of Mississippian age. The limestone is a dark blue, semi-crystalline rock, in which zaphrentoid corals seem to be the most abundant fossils.

Above the Lower Blue comes the Lower Intercalated series, 600 feet thick, the lowest member of which is a sandstone 100 feet thick. Above this come frequent alternations of siliceous and calcareous sediments (silicilutites and calcarenites). Two parallel sections measured on the steep bare walls of the canyon three-fourths of a mile apart showed considerable thinning of these beds toward the east, even in this slight distance.

Above these intercalated beds is a great limestone succession 5000 feet thick, broken only in two places by very dark calcareous shales, one about a thousand feet below the top and the other about the same distance from

²⁶ J. E. SPURR: "Geology of Mercur District, Utah," U. S. Geol. Surv., 16th Ann. Rept., Part II, pp. 371-377. 1894.

the bottom. From the lower shale, a bryozoan and brachiopod fauna was obtained, which Professor Schuchert assigned to the Burlington-Keokuk horizon. The upper limit of the Great Blue limestone merges gradually into the Upper Intercalated series, which, with its frequent alternations of siliceous and calcareous beds, is in sharp contrast with the heavy blue layers of the Great Blue limestone. Between these two formations, Schuchert places the division between the Carboniferous and Mississippian. The Mississippian in the Oquirrh is thus made somewhat over 6000 feet, and the upper division, counting the Weber quartzite exposed at Bingham and over a large area to the north, between 15,000 and 18,000 feet.

To facilitate the discussion and bring out the relationships which exist among the Carboniferous formations of the Oquirrh, Wasatch and Uinta mountains, columnar sections from these three ranges taken in an approximate east-west line through the Cottonwood district have been drawn side by side in Fig. 4. The distance between Mercur and Big Cottonwood Canyon is about equal to the distance from Big Cottonwood to the western Uintas, being in the neighborhood of thirty-five miles.

The much greater development of Mississippian and Pennsylvania strata in the Oquirrh Mountains is seen at a glance. The corresponding parts are indicated by the dotted lines. It becomes apparent at once that the unconformities shown in the Wasatch and Uinta sections represent a long interval of erosion. Farther to the east, in Colorado, this same unconformity has been reported between the Mississippian and Pennsylvanian formations, and the same explanation no doubt applies there as well. It seems reasonable to suppose that the Mississippian was represented by much thicker formations in these sections at the beginning of Pennsylvanian time than is shown at present. The Great Blue limestone was very probably represented in them all, but just when the area of the Wasatch and eastward into Colorado was lifted and exposed to erosion cannot be definitely stated. It was probably toward the end of Great Blue time. During the long period of erosion which followed, most of the Mississippian limestone was worn away and transported elsewhere to be deposited as calcareous mud or, if dissolved, remain in solution in the sea water. The new shore line receded westward until it came to occupy some position between the Wasatch and Oquirrh mountains. Here it seems to have remained for a long time, as we may judge from the nature of the great deposits which formed in the Oquirrh Mountain area.

Above the Great Blue limestone, we have the Upper Intercalated series, which on the Mercur side of the divide is from 5000 to 6000 feet thick, but it continues east of the divide and may be as much as 10,000 feet in

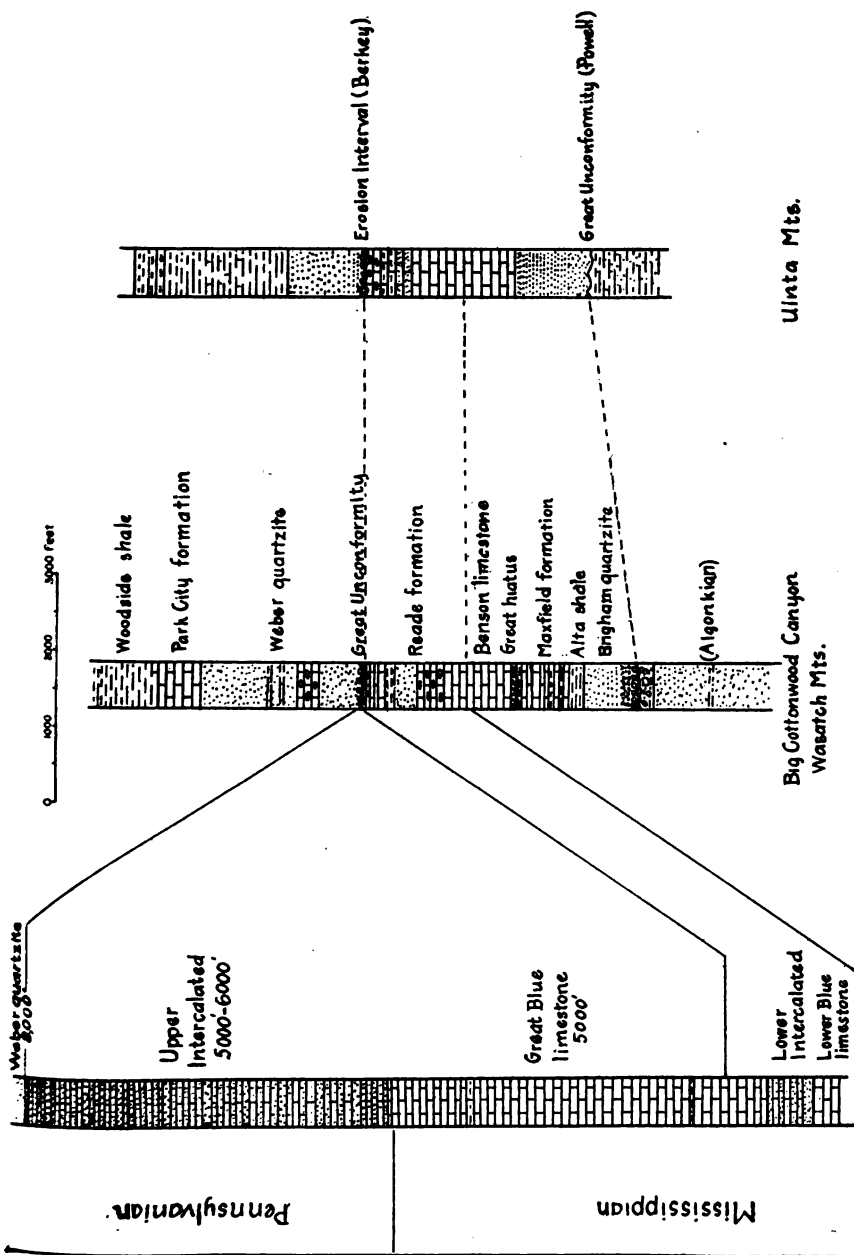


FIG. 4. SECTIONS TO SHOW THE GREAT UNCONFORMITY BETWEEN THE MISSISSIPPIAN AND PENNSYLVANIAN IN THE WASATCH AND UTA MOUNTAINS, AND ITS VALUE IN THE OQUIRH MOUNTAINS

Mercur, Utah

Oquirrh Mts.

thickness before the Weber quartzite is reached. This series is described as consisting of numerous alternations of sandstones and sandy limestones. many of the beds presenting for considerable distances complete intermediate stages between the more calcareous on the one hand and the more arenaceous on the other. The presence of marine fossils throughout the series, in the more calcareous layers, may be taken as good proof that the deposit was formed in the sea and probably not far from the shore. The lime muds from the great limestone area toward the east became mingled with the sands of the shore, giving rise to the calcareous sandstones which are so prominent a part of these intercalated beds. The Mercur report leaves much to be desired in the matter of details concerning the organic record. With the excellent exposures to be had there and the obvious importance of knowing what fossils are imbedded in these rocks, it is to be hoped that this section will soon receive the careful study which it deserves. Enough has been done, however, to determine the age of the series as a whole, and to warrant the comparison that is here made. Following Spurr's report, we may assume that deposition was continuous in the Oquirrh Mountains. The hiatus, therefore, in the Wasatch and Uinta sections, represents a long erosion interval, comparable in time to the period necessary for the deposition of the 6,000 to 10,000 feet of intercalated limestones and sandstones. It seems also probable that it was even much longer, as will be brought out in the discussion of the Weber quartzite problem (see Fig. 4).

PENNSYLVANIAN STRATA

Weber Quartzite

Following the basal Pennsylvanian conglomerate in the Big Cottonwood section is a quartzite 1000 feet thick, in which no fossils were found. The sand grains are of fairly uniform size, giving a rock of even, rather fine-grained texture. The bedding is prominent and regular in layers of moderate thickness. While the surface has a brownish appearance, the freshly broken rock is quite colorless. Ripple marks, cross-bedding and other shallow water characters seem singularly wanting, yet the fine detrital nature of the deposit certainly points to shallow water deposition. In the upper portion, thin limestone layers are intercalated between the sandy beds, and a succession of mainly cherty blue and white limestones follow, making up several hundred feet in thickness. These are well exposed on the north side of the canyon, just opposite the government forest station. Above these limestone beds, the quartzites reap-

pear and give another thousand feet of fine-grained white rock. The series thus defined above the disconformity which terminates the Mississippian strata constitutes what is here called Weber quartzite. In the Park City district to the east, Boutwell²⁷ reports only the upper portion of the Weber quartzite as seen in outcrops.

"The middle and basal portions of the formation, which are not present in this area, outcrop in prominent cliffs just south of the district. Except for a few thin limestone beds near its top, the middle portion is massive quartzite, but in the lower part, the intercalated limestone members increase in number and thickness."

The middle and basal portions here mentioned correspond with part of the upper and middle parts of what is called Weber quartzite in this report. The thickness given in Boutwell's section is 1350 feet, which he regards as too small and gives a tentative estimate of 3500 feet. The exact thickness is still doubtful, as continuous exposures could not be found within the Cottonwood district, but 3500 feet is probably too great. Somewhat more than 2000 feet is thought to be more nearly correct.

In the type locality in Weber Canyon, 30 miles to the north, the Fortieth Parallel geologists²⁸ have given the thickness as 5000 to 6000 feet. This figure has been questioned by Blackwelder,²⁹ who follows Weeks³⁰ and separates the lower red beds of that section from the Weber and calls them the Morgan formation. There is, however, no doubt that the development of the Weber quartzite in Weber Canyon is considerably greater than in Big Cottonwood and that the thickness is subject to variation from place to place. In less than 15 miles north of Weber Canyon, it disappears altogether and the Park City limestone which overlies the Weber in all of the southern sections rests directly on Mississippian limestone. Blackwelder describes the unconformity as one of low angular discordance, the beds of early Mississippian age being slowly truncated, over the edges of which the Park City limestone rests. As we go southward, the Morgan formation and Weber quartzite appear between the Mississippian limestone and Park City formation. The Park City beds thus overlap the Weber quartzite and Morgan red beds, and going still lower rest on early Mississippian.

It is also important to note that in Weber Canyon, the Morgan formation rests on much higher Mississippian beds than in the northern sections. This fact may be explained in several ways. The presence of a

²⁷ J. M. BOUTWELL: U. S. Geol. Surv. Prof. Paper 77, p. 45.

widespread unconformity between the Pennsylvanian and Mississippian throughout Colorado, Wyoming, northern Arizona and all of Utah, with variable amounts of the Mississippian strata present in the different sections, may explain the absence of the Upper Mississippian strata in Blackwelder's northern sections. That this was a long period of erosion has already been explained, and the disappearance of the Weber northward may well be by natural thinning due to overlap. The position of the Weber quartzite in the Oquirrh Mountains above the intercalated beds, which are not represented in the Wasatch sections and those farther to the east, indicates that the hiatus at the base of the Morgan formation in Weber Canyon represents a considerable interval of time. The Morgan formation is considered to be of very local extent and may be taken to be a part of the Weber.

The relation of the Weber to the overlying Park City formation is described in the early reports as one of complete conformity. In the Big Cottonwood section, the division line is covered in most places and was not studied in detail by the writer. The section given by Boutwell²¹ in the report on the Park City district, as the type section for that area, was measured in Big Cottonwood Canyon, on the ridge east of Mule Hollow. This section was verified by the writer and may be taken as representative for the upper divisions of the Weber quartzite and higher formations. Of the contact in question, the Park City report reads as follows:

"No unconformity was observed with the underlying Weber quartzite, or the overlying shale, or within the formation (Park City). Accordingly, it would seem that sedimentation proceeded unbroken from Mississippian time through that part of Pennsylvanian which is represented by the Park City formation."

Blackwelder²² on the other hand concludes from his studies in Weber Canyon that there is an unconformity. He says:

"The Weber quartzite is limited above by an irregular eroded surface, which is not exactly parallel to the bedding; it was subject to disintegration; and not merely one, but a variety of beds in the formation were exposed, as is shown by the large amount of chert as well as quartzite in the breccia. On the whole, the evidence for the existence of an unconformity at this horizon seems to be conclusive.

"The importance of the unconformity is uncertain. If the Weber quartzite is

and should represent but a brief land interval. If, however, the Weber quartzite was once far more extensive than now, and if it has been removed from the northern part of the Wasatch region, and elsewhere reduced to a varying thickness by erosion within the Pennsylvanian period, then the interval must have been relatively long. It is significant in this connection, that the fragments of quartzite in the basal breccia were quartzite, rather than sandstone, when broken from the parent ledge, during the erosion interval, as is shown by the preservation of sharp corners and edges."

The exact amount of time represented, if we grant the presence of an unconformity between the Weber quartzite and the Park City formation, can only be decided by finding out the ages of these two members. If the Park City formation is Pennsylvanian in age and the Weber quartzite is late Pennsylvanian, as the Oquirrh mountain sections indicate, then the interval must be short and relatively unimportant and cannot explain the great variation in thickness of the Weber and its total disappearance in sections not far distant from its type locality. If, on the other hand, the Park City formation is made Permian in age and the Weber quartzite early Pennsylvanian, then a great hiatus must exist between the two formations. Such a one should be well marked, and we should expect it to be especially easy to recognize where the Weber is thinnest by its most extensive erosion. The presence of a basal conglomerate with well-rounded quartzite pebbles should be expected within short distances of the present occurrences of the parent body. Again, if the Park City formation is Permian in age and the Weber late Pennsylvanian, a small hiatus may exist between the two, such as has been described by Blackwelder. It may be safely assumed that the Park City beds are late Pennsylvanian or early Permian, and in view of the high position of the Weber quartzite in the Oquirrh mountain sections, it seems clear that no great erosion interval exists between these two formations. The thinning of the Weber is more easily accounted for by overlap, as it was undoubtedly laid down on a surface that had been long exposed to erosion.

PARK CITY AND LATER FORMATIONS

The Park City formation has been named from the Park City mining district within which it carries bonanza ore bodies. No good exposures are known, however, from the Park City area, and within the area specially studied for this report, the formation does not occur. It is of interest, nevertheless, to give the characters of this formation some consideration from the widespread occurrence of this member in the central Wasatch and northward.

The Park City formation lies between the Weber quartzite and the red beds of the Woodside shale, and, in the type locality on the north side of Big Cottonwood Canyon, it has a thickness of about 600 feet. As exposed there, it consists largely of limestone with intercalations of sandstone and quartzite. Its differentiation below from the Weber quartzite is readily made by the appearance of calcareous layers which soon give way to a thick bed of limestone. As before stated, in the central Wasatch this transition indicates continuous deposition from Weber into Park City time. The occurrence of limestones nearly as extensive as those of the Park City formation within the typical Weber is well known, and this suggests that the Park City beds mark the recurrence of one of these periods of limestone formation when typical marine conditions prevailed.

In the older reports, the upper coal measure limestones represent this horizon. They were especially noted for the abundant fauna which they carry and have usually been regarded as of Carboniferous age. Of late, however, some tendency is shown to place them higher in the series, possibly in the Permian. In the correlation table here given, the interpretation of the various workers is placed at the right and that of the writer on the left. This view is supported by the fauna and stratigraphic relations which are better shown in Dry Canyon, to the north, than in Big Cottonwood Canyon. There is in that section between 500 and 600 feet of red shales and brownish sandstones between the Meekoceras beds of the Lower Triassic and the upper fossiliferous portion of the Park City formation. These seem to rest with low angular unconformity upon the Park City beds and carry an abundance of a single species of *Lingula* in the beds next to the contact. Faulting is frequent in this area, and the apparent discrepancy in dip between the two sets of beds may be due to that cause, but a search failed to reveal evidence of faulting. From the nature of the beds of red shale and brownish sandstones, it might be expected that they should bear a relation of unconformity, or at least disconformity, to the typical marine beds upon which they rest. From the widespread occurrence of Permian red beds in the west, these are thought to be of that age. The fauna of the upper part of the Park City formation indicates their Carboniferous age. Prominent forms are:

Productus multistriatus
Productus subcostatus
Spiriferina pulchra
Spirifer cameratus
Lingulodiscina utahensis

In Red Butte Canyon, the next gulch to the south of Dry Canyon, occurs a heavy conglomerate and a considerable thickness of purple sandstone. These purple beds were called Permian by the geologists of the Fortieth Parallel Survey. Overlying them are the strongly cross-bedded red sandstones which form the prominent red cliff at the mouth of the canyon, from which it has derived its name. These are the "Triassic red beds" of Hague and Emmons. The discovery of the *Meekoceras* fauna several hundred feet below the purple sandstones has carried the lower limit of the Triassic down below what was called Permian into those beds which were mapped as upper coal measures by the Fortieth Parallel geologists. The simple synclinal structure for this region shown on the Great Basin sheet of that survey is now also known to be more complicated, including at least one large anticline and another syncline to the south of Emigration Canyon. The new geologic map of this region now being prepared by Mr. N. C. Christensen and Dr. F. J. Pack will look very different from the present one, and it is expected that the separation of the Jurassic, Triassic, Permian and Carboniferous can be definitely accomplished in this region. For the present, the interpretation here given (page 126) is thought to be very near the true one.

TENTATIVE CORRELATION TABLE

Period	Central Wasatch	Northern Wasatch	Wasatch Range
		Weeks, Kindle, Blackwelder and Walcott	Hague and Emmons (40th par.)
c	Nugget sandstone	(absent)	Jurassic
	Ankareh shale Thanes formation	(absent)	Triassic Red Beds
n	Woodside shale	(absent)	
lvanian	Park City formation Weber quartzite (absent)	Park City formation Weber quartzite Morgan formation	Upper Coal Measure limestone Weber quartzite
ippian	Reade formation	Madison limestone	
an	Benson limestone	Jefferson limestone	
	(absent)	Paradise limestone	Wasatch limestone (Ogden quartzite and Ute limestone eliminated)
ian	Maxfield formation (unfossiliferous limestones and shales)	(Geneva formation Boxelder limestone)	
	(absent)	St. Charles formation	
	(absent)	Nounan formation Bloomington formation Blacksmith formation Ute formation Langston formation	Primordial slates and quartzites (Big Cottonwood series)
	Quartzite and shale	Brigham quartzite	
ian	Big Cottonwood quartzite and shale series	Quartzites and shales near Huntsville	
n	Gneiss and schist	Gneiss and schist	Archean gneiss and schist

STRUCTURE

INTRODUCTORY STATEMENT

The first unified account of the larger structural features of the Wasatch Mountains is that given by the geologists of the Fortieth Parallel Survey.³³ In a broad way, these early observations have been verified by the more recent studies of particular parts of the range, but many important new facts have been added and some of the original conceptions greatly changed.

Vital to the first conception of Wasatch structure was the supposed presence of an Archean axis which had the same trend as the present range, north and south, on the flanks of which were deposited the early Paleozoic sediments, until they completely buried the lofty Archean peaks. At the close of Mesozoic time, profound plicating and plateau forming movements threw the thick conformable Paleozoic and Mesozoic sediments into great pitching anticlinal and synclinal folds with axes mainly north and south. After a period of erosion during which the upper parts of the folds were planed off, profound faulting along the present western faces of the range took place, tilting the old surface eastward on the uplifted eastern side. Upon that uplifted block, erosion has carved the present relief.

It is now known that the main body of supposed Archean, the Little Cottonwood granite, is intrusive, and the original conception of a pre-Cambrian protaxis has been entirely discarded. Folding is known to be much more intense than originally thought, and large overthrusts have been discovered from Ogden northward to Willard and in the Cottonwood district.

Since the overthrusting, there has been considerable deformation and faulting which have introduced the most complicated tectonic relationships.

STRUCTURE OF THE CENTRAL WASATCH

The central Wasatch is an exception, structurally, from the general anticlinal aspect of the range as a whole. Within this area, extensive intrusion of granite and granodiorite and widespread extrusion of andesitic lava, with their accompanying phenomena of metamorphism, are grandly displayed. Encircling the main intrusive body, the Little Cottonwood granite, are steeply inclined quartzites, shales and limestones, with varying age ranging from pre-Cambrian to late Mesozoic. Dipping

³³ U. S. Geol. Expl. 40th Par., Vol. II, Sect. 3 & 4.

quaquaversally from the nucleus of granite, this great series of sediments forms the eastern half of a huge dome abruptly cut off on the west by a profound fault. The western half was depressed and is now entirely covered by the deep accumulation of rock waste forming the floor of the Salt Lake Valley. Eastward, the Carboniferous and Triassic formations are breached by an irregular stock of fine-grained granodiorite which culminates in Clayton Peak. Beyond this line of elevation, which forms the present divide, an extensive flow of andesite was poured out in an elongated synclinal depression that separates the Wasatch from the western Uintas. It is significant that the anticlinal fold of the Uinta range is in line with the eastward prolongation of this domed arch and that they are connected beneath the igneous covering by the Kamas prairie syncline.

Little Cottonwood Granite

The structural relation of the Little Cottonwood granite to the sediments which flank it upon all sides has been variously interpreted. By the geologists of the Fortieth Parallel, the contact was described as one of sedimentary unconformity; and the granite was thought to be older than the quartzites that appear to overlap it. The absence of a basal conglomerate was noted, and the whole situation was thought to be extraordinary. At that time, the intrusive occurrence of granite had not been conceived, and the indications of contact and regional metamorphism escaped notice, so that while the evidence of a sedimentary contact was not in accord with conditions commonly regarded as necessary, the relation was still held to be due to sedimentation.

In 1880, Geikie⁸⁴ visited this region and later published his conclusions. He found structural evidence that led him to regard the granite as intrusive, and probably post-Carboniferous in age, rather than pre-Cambrian as given by the Fortieth Parallel geologists.

In 1900, Boutwell visited Little Cottonwood Canyon and examined the contact of the granite and quartzite on the ridge south of Twin Peaks. Here he found dikes of granite extending up into the quartzite and sills of granite leading off laterally from the dikes. Inclusions of quartzite in the granite were also observed, and the intrusive nature of the granite was thus established. These results were verified by Emmons⁸⁵ who later published his conclusions regarding the granite as in-

⁸⁴ A. GEIKIE: "Archean Rocks of Wasatch Mountains," *Am. Jour. Sci.*, 3rd Ser., Vol. 19, pp. 363-367. 1880.

⁸⁵ S. F. EMMONS: "Little Cottonwood Granite Body of the Wasatch Mountains," *Am. Jour. Sci.*, 4th Ser., Vol. 16, pp. 139-147. 1903.

trusive and pre-Jurassic in age and the chief folding of the sediments as Jurassic.

The Little Cottonwood granite has commonly been regarded as laccolithic in structure, since its intrusive character has been known. While the inclosing quartzites do dip away in all directions from the central igneous mass, suggesting that they may have been arched up by the intrusion, the essentials of laccolithic structure are nowhere shown. The far-reaching metamorphic effects of the granite upon the contiguous sediments, its uneven ragged contact on all sides and its thorough crystalline coarse texture all indicate a mass of irregular shape and great size. It would seem advisable, therefore, to speak of the Little Cottonwood mass as a stock and reserve the term laccolith for the more special type of intrusive.

As to the geologic data of the intrusion, there is also much uncertainty. The latest sediments cut are Algonkian, and possibly Lower Huronian, in age. If the mass were known to be laccolithic, then the latest sediments affected by the arching would give the desired information; or, if the doming of the strata is due to the intrusion of the granitic stock, then the age might quite easily be stated as later than the youngest beds that are involved. But it is difficult in this region of strong folding to distinguish between the flexing due to regional folding and that due to a special cause such as intrusion, where the two come so close together.

A few general considerations may lead to a closer approximation of the date of the intrusion than can be made from the sediments cut by it. The Little Cottonwood granite mass lies in an east-west zone of eruption which has been active in some parts in post-Triassic, probably Tertiary time. At Bingham, it is marked by a large body of post-Carboniferous monzonite and trachytic extrusion. Still farther west, the sheets and dikes of the Mercur and Ophir districts are in the westward continuation of this belt. Just east of Alta is a large irregular stock of granodiorite which cuts Carboniferous limestones and adjoining it to the east is the Clayton Peak mass of quartz diorite which cuts Triassic strata. The interrelations of these three main intrusive bodies have not been discovered in the field. They are not in surface connection with each other, so far as known, but a northeast-southwest system of dikes and veins is characteristic of the whole region; and closely associated with the ore bodies. These dikes are clearly later than the folding, since they do not show deformation and from their similarity to the larger intrusive masses they may be assumed to have come from them, though none has actually been traced to the junction point. They are seen to disappear beneath rock debris within a few hundred feet of the larger bodies, however, and

are surely connected with them. If such a contact could be seen, it would shed much light upon the relative ages, but in the absence of actual proof, we may only reason about them.

If we assume that the Little Cottonwood granite, the Alta granodiorite and the Clayton Peak quartz diorite are connected below, as is commonly done, they are probably not of very different ages and may be taken as being as young as the most recent sediments cut. This would make them post-Triassic. If the fracturing of the beds and intrusion of the dikes came after the folding, which is thought to be late Cretaceous, and if this occurred contemporaneously with the intrusion of the larger bodies, as might be the case, then the Little Cottonwood granite, as well as most of the other igneous masses, are post-Cretaceous.

The extrusive andesites of the Kamas prairie to the east are in contact with the Vermillion Creek beds of the Eocene as reported by the Fortieth Parallel geologists.²⁶ They are thus later than these early Eocene beds and represent the latest igneous activity of the region. Their relation to the porphyritic dikes and granitoid intrusives of the Cottonwoods is not known, but they are probably much later. The Little Cottonwood granite was no doubt uncovered during the period of erosion which followed the post-Cretaceous folding. The extrusions came after the upturned Paleozoic and Mesozoic beds had been strongly truncated, covering the old surface in the depression between the Wasatch and Uinta mountains.

The date of the intrusion of the granite will presently be further discussed when the problem of overthrusting and faulting near Alta is taken up. From the above, it appears that the granite probably came in immediately preceding or possibly accompanying the folding in post-Cretaceous time. The eruptive andesites are post-Vermillion Creek and belong undoubtedly to the Tertiary period.

STRUCTURE NEAR ALTA

In the Alta region, the most obvious structure is an eastward dipping monocline, which to the north and south slowly curves westward, in accordance with the general dome structure for this part of the range. The strata stand at a considerable inclination, averaging between 35 and 45 degrees, but locally the dip may be much more and in some parts notably less. This simple structure is much complicated in places by folding and faulting. The folds are confined to a zone within the sedimentary series, the formations above and below having the ordinary monoclinial attitude. This condition has been brought about by over-

²⁶ S. F. EMMONS: U. S. Geol. Expl. 40th Par., Vol. I, pp. 586-587. 1878.

thrusting, the weaker members in the lower part of the overthrust mass having been rolled together in such a way as to make it almost hopeless to try to make out any regular structures. Small Z-shaped folds have resulted in several places, and in others, overturned and isoclinal folding may be observed. North and south of Alta where the disturbance seems to have been the greatest, the weak shales of the Cambrian system have been drawn out into long tongues in the midst of the quartzites, entirely isolated from the limestones which normally overlie them. The dynamics by which this was accomplished in a region so complicated can hardly be explained. The strata plainly show that they have been torn loose from their normal position in the sedimentary series and involved in the zone of shearing so as to be widely separated from their former position.

In Big Cottonwood Canyon, above the Alta black shale exposed near the old Maxfield mine, rises a great series of limestones. Below the shale is a thickness of about 1200 to 1500 feet of Cambrian quartzite, and below that the Algonkian quartzite slate series 11,000 feet thick forms the base of the section. There is thus in Big Cottonwood Canyon a great limestone series overlying the Alta shale. These may both be traced south-east across the canyon where the limestones are seen to form the top of Kessler's Peak. Still farther along the strike, they cross South Fork and are best seen as the chief rocks making up the Reade and Benson ridge, on the east wall of South Fork. They may be continuously followed south into Little Cottonwood Canyon where they form the ore-bearing zone north of Alta. The Cambrian black shale can be traced along in the same way and some of the underlying quartzite, but just below Alta a second lower series of limestones outcrops in bold cliffs on both sides of the canyon, facing Superior and Peruvian gulches. To one familiar with the Big Cottonwood succession where no limestones appear below the Cambrian rocks, this condition at once suggests an overthrust. An examination of the rocks below the lower limestone revealed the Cambrian black shale as the first member and the familiar Lower Cambrian quartzites and the upper part of the Algonkian quartzite and slate series as the downward continuous succession. Below the upper limestones, which were traced over from Big Cottonwood, are, in order going down, the Cambrian black shale (Alta), the Lower Cambrian quartzite (Brigham) and the upper part of the Algonkian series which rests upon the lower limestones. There is thus a complete duplication of the strata from the

have overlooked this relationship. They seem to have been prejudiced from the similar relations which they had observed in the range to the north, in Weber and Ogden Canyons. In describing the Big Cottonwood section, King³⁷ has the following to say:

"Next above the Cambrian lie 1,000 feet of Ute limestone, which for the most part is very light colored, highly crystalline and characterized by peculiar cloudings of color that extend across the beds near the bottom of the series, and at one or two horizons near the top it is noticeable for containing a large proportion of tremolite, and under the microscope it is seen to be highly siliceous, the silica appearing as rounded glass grains of pellucid quartz. The outcrop extends up the hills on both sides of the canyon and to the south is conspicuous upon the divide, from which it descends into Little Cottonwood and in the valley a little way below Alta exposes a fine precipitous cliff, the result of a fault (the Superior fault of this report). Here again are seen the same highly crystalline, almost marble-like condition and the same prevalence of tremolite and silica. Under these circumstances it is not at all remarkable that the beds contain no fossils, but it is unquestionably Silurian, as will be seen later.

"Above the limestone occurs the white granular body of Ogden quartzite, which is here reduced in thickness to about 800 feet. It may be traced up the hill to the south and forms an interesting saddle in the ridge top, between the Ute limestone and the bold masses of Wasatch limestone which directly overlie it. Here are but limited traces of the thin body of greenish argillites that farther south, in the region of Rock Creek, were found on both sides as bounding-beds to the Ogden body."

The presence of the "Ogden" quartzite between the "Ute" and "Wasatch" limestones in the Big Cottonwood section seems to have been inferred from its prominent appearance on the ridge above Alta. In Big Cottonwood Canyon, no such quartzite member is exposed. The outcrop at the head of South Fork, having the described position between the two limestone members, can be traced northward along the strike of the beds into Big Cottonwood Canyon, where it appears below the lowest limestones there exposed. It therefore clearly belongs to the Cambrian. This fact might easily have been discovered had the early geologists attempted to explain the presence of a black shale above the "Ogden" quartzite on the ridge above Alta. For some reason this important horizon marker was overlooked or disregarded altogether. The "limited traces" above referred to are hard to harmonize with the good exposure of this Cambrian shale at the south end of the Reade and Benson ridge, where it shows its typical thickness, between 150 and 200 feet. The lower occurrence, below the "Ute" limestone, seems to have been noted, though the

³⁷ C. KING: U. S. Geol. Expl. 40th Par., Vol. I. Sys. Geol., pp. 167-168. 1878.

thickness and exposure there are hardly more favorable for observation. The strong contrast between the black shale and the almost white quartzite makes the presence of the shale easy to recognize and renders it one of the best guides to the surface geology of the region (see Plate III, A).

Alta Overthrust

As already stated above, there is complete stratigraphic evidence of a large overthrust in the vicinity of Alta, for which the name Alta overthrust is proposed. It has been traced north from the locality where it was first discovered northwest of Alta into Big Cottonwood Canyon and south into American Fork. There can be little doubt, however, that it extends much farther in both directions. The dip of the overthrust beds is not very different from that of the strata upon which they rest, so that the attitude of the beds above the thrust surface furnished no clue to the relationship. The strong contrast in color and lithologic characters between the various stratigraphic members soon led to the recognition of a complete duplication of beds. The other factors were then soon discovered. Evidence of intense dynamic action was found in the highly folded and contorted conditions of the weaker strata. Rapid variation in the thickness of the beds, and the complete disappearance of some of them, above and below the thrust surface were noted.

The accompanying diagram (Fig. 5) shows the relation of the beds above and below the thrust surface as they occur between Alta and Argenta, a distance of about four miles. The succession at the right is the same as that seen in the photograph (Plate IV, A). As we go northwest, the lower members of the series above the thrust line TT^1 , as well as the limestones and shale below it, disappear, so that when Argenta is reached these beds are missing. The Cambrian quartzite has apparently become much thicker, being nearly twice as thick as it is in the two exposures near Alta and at the head of South Fork. The only duplication of strata shown in Big Cottonwood is the Cambrian quartzite, and that shows itself in the increased thickness of the beds, the exact line of separation not having been observed. On the north slopes of Kessler's Peak coming around from Mineral Fork, the thrust surface disappears beneath a heavy mantle of débris, and where it emerges on the north slopes of Big Cottonwood, it has not been found again.

From Alta southward, the thrust surface is more easily traced. The lower limestones outcrop all along the east wall of Peruvian Gulch to

eral Flat. The lowest overthrust member is quartzite, plainly seen as the capping of Bald Mountain directly south of Alta (see geologic map, Plate VI). All along Peruvian Gulch and in American Fork, this seems to lie conformably upon the limestone. Both the limestone and the quartzite being very resistant, the contact is often sharp with very little crumpling or brecciation. The truncation of the beds, however, shows beyond any doubt the secondary nature of the structure. More-

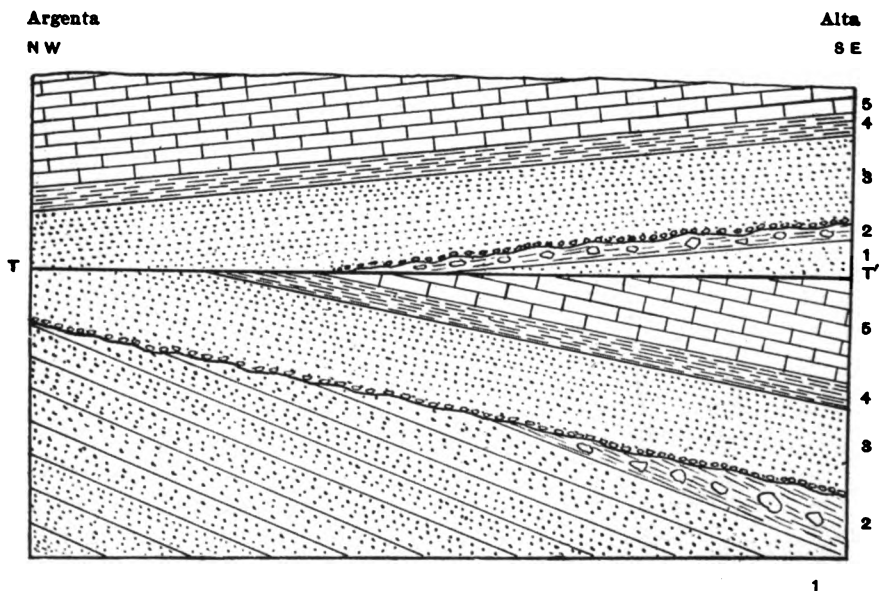


FIG. 5. SECTION BETWEEN ARGENTA, IN BIG COTTONWOOD CANYON, AND ALTA, IN LITTLE COTTONWOOD

Relation of the overthrust Paleozoic and Proterozoic strata to beds of the same ages below

1 = Algonkian quartzite. 2 = Algonkian "conglomerate." 3 = Cambrian quartzite
4 = Cambrian shale. 5 = Ordovician and Devonian limestones. TT' = Thrust surface

over, in many places crumpling and brecciation have occurred—as should be expected. In all such cases, the limestones have been the least affected, but the overthrust quartzites and shales have suffered strong deformation. The best example of this condition is seen on the slopes northwest of Alta. The black Cambrian shale has here been drawn out into a long tongue in the midst of the quartzite, showing every inclination from strongly overturned folds near the Columbus mine to a vertical position farther up the hill. The quartzite is folded and smashed in such a way as to be chaotic, individual blocks being traceable for short distances only.

In the mine workings on this hill, the discontinuity of the beds seen on the surface is also shown. No regular structure can be followed very far within the quartzite, or overthrust zone. The deeper workings which drift far to the westward finally enter the limestones below the thrust mass, and here the dip is regular to the east. The thrust contact dips strongly to the east on the surface, but deeper it gradually flattens out.

The age of the overthrust is not positively known, but there can be little doubt that it occurred during, or at least at the close of one of the periods of folding in late Mesozoic time. The folding of the Wasatch is generally assigned to the close of the Cretaceous, but King²⁸ has described an unconformable contact between the local Dakota beds and the Jurassic and older sediments exposed along Mountain Dell road in the upper part of Parley's Canyon. The difference in dip of the beds is given as about 30 degrees, and the Cretaceous strata rest on the truncated edges of all of the older Mesozoic and Paleozoic formations, but elsewhere the Cretaceous is described as conformable with the older series, and this relation is the commonly accepted one. More work will have to be done to settle this question. If there was important folding at the close of the Jurassic, the overthrust in the Cottonwood region could have occurred then. It certainly took place before the intrusive action occurred in this district, as is evidenced by the independent manner in which the dikes cut through the basal series and overthrust blocks. This event followed or accompanied a period of northeast-southwest fracturing and faulting which preceded the period of mineralization. Still later, important faulting transverse to this first fracture line occurred, of which the Superior fault is the best known example. The overthrusting, therefore, appears to have happened along with or following the first dynamic disturbance in the region. Later warping has deformed the thrust surface and tilted the masses at a high angle.

Farther north in the range, Blackwelder²⁹ has described similar structures which he thinks were made at the same time that the Paleozoic rocks were folded, which is generally assigned to the close of the Cretaceous period, but he says "It seems to be a fact that the Lower Eocene (Wasatch) sediments cover the outcrop of the overthrusts in several places, thus indicating that the folded and overthrust structures had been deeply eroded." It is quite likely that these two districts less than fifty miles apart suffered overthrusting at the same time and that whatever period is deduced for one will be found to be the same for the other.

From southeastern Idaho and northern Utah, Richards and Mansfield⁴⁰ have described a great overthrust which involves strata of late Cretaceous age. The oldest rocks which have been found concealing its trace are the early Eocene conglomerate of the Almy formation,⁴¹ making the possible range of age from late Cretaceous to early Eocene. This agrees closely with Blackwelder's determination for the Willard overthrust near Ogden, Utah.

The latest beds involved in the Alta overthrust are Pennsylvanian within the area studied, but from the general fact that overthrusting accompanies or follows strong folding, the overthrusts of the central Wasatch must belong to the late Mesozoic and are probably of the same age as the great Willard and Bannock thrusts.

The trace of the Alta overthrust has a trend north-northwest, while the thrust surface dips strongly to the east with the general monoclinical structure of the region. This leads to the belief that the movement was from east to west, though this is only tentative. The overthrust block seems to be continuous for eight or ten miles to the east, where it disappears below the quaternary beds of Kamas and Weber valleys. More extended work will be needed, however, to show definitely that the direction of thrusting is as above indicated.

Blackwelder thinks the overthrusting near Ogden came from the east, but Richards and Mansfield have questioned the correctness of this determination, as they believe it came from the west. There is thus a difference of opinion in a region perhaps better adapted to the determination of this question. It might be said, however, that the unsymmetrical anticlines of the Cottonwood region are steepest on the west, and in one or two cases seem to be overturned in that direction, suggesting strong lateral pressure from the east.

The structural relations along the trace of the Alta overthrust are shown in the structure sections accompanying the geologic map.

A Minor Overthrust

Immediately south of the town of Alta there is a mass of limestone, shale and quartzite which stands nearly vertical, dipping slightly to the west. In Collins's Gulch, the strata dip eastward at an angle of about 25 degrees. Across the ridge to the east of the Albion tunnel the quartzites

which is overturned and does not match with the lower beds on either side. All attempts to explain the structure as a syncline, or overturned anticline, fail when the succession of beds is noted, leaving the only reasonable basis of explanation that of an overthrust block.

Faults

In a region of such complicated structure, faulting may be expected to occur. Dislocations are met with in every mine, but those on a big scale are few in number. Whether large or small, they appear to belong to two systems of fracturing, but movement has probably occurred more than once in each system. The directions of these two sets of fractures are respectively north-east and south-west for those carrying the ores and dikes, and northwest-southeast. These correspond to the dip and strike of the Alta monocline and may therefore be classified as dip faults and strike faults.

The earliest displacements are those in which the fissure veins carrying the ore were found. These have a fairly constant direction, N. 70° E., and no doubt belong to the same period of fracturing which gave rise to the lode deposits of the Park City district which lie in the path of their northeastward extension. Into some of these, the dikes which are common in the southern part of the district were injected, and it is thought that the ore-bearing solutions came up in others at the same time, or immediately following, depositing the ores. The displacements above this first set of fractures do not appear to have been very great. They are probably more in the nature of great cracks which were formed through the effects of intrusion of the larger bodies of igneous rock to the east and west, as inferred from the correspondence of their direction with the general trend of the intrusives. On the other hand, when compared with the general dome structure of the region they are radial and might be considered as tension cracks made when the region was thrown into its present arched condition.

After the formation of the ore deposits of the district in the northeast-southwest fissures, a second period of faulting occurred, having a transverse direction to the first set of fractures. This is shown in the northwest-southeast faults encountered in many of the mines, where they invariably displace the ore bodies. A notable case is the great Atwood "slip" which cut out the ore of the famous Emma mine. Many other examples are known in the various mining properties.

The displacements of these strike faults are much greater than those of the earlier fractures. The one occurring in Superior Gulch running north into South Fork appears to have the greatest throw and has been

called the Superior fault. A second one of great size cuts across the ridge from the head of Silver Fork into the Alta basin. It is seen most clearly on the ridge northeast of the Emma mine, where the fault breccia has weathered into relief, standing up like a great wall. This fault will be described as the Silver Fork fault. In all of these movements, the displacements are more in the vertical direction, lateral shifting being not so frequently met with.

Superior fault.—The Superior fault as shown upon the map (Plate VI) can be traced from the mouth of Superior Gulch in Little Cottonwood Canyon northward into South Fork. On the top of the ridge, it is clearly marked by a wall of breccia which stands up ten feet above the general level of the surface. The crushed zone marked by the breccia may be followed northward for nearly a mile. In the upper tunnel of the Cardiff mine, it is well shown for a distance of a thousand feet along which the hanging wall is quartzite and the foot wall very hard limestone.

From all indications in South Fork, where it was first encountered, it may be explained as a normal fault with a throw of about a thousand feet, but observations from the Alta side of the divide clearly show it to be a reverse fault of less magnitude, the displacement being about 600 feet. The limestones on the west are lifted. They belong to the lower series exposed on the east wall of Superior Gulch and not to the limestones of the Reade and Benson ridge as at first supposed. This was not understood until the overthrusting which duplicated part of the series was discovered at Alta. The limestones are all of the same age but they occur in two series separated by nearly a thousand feet of older quartzite belonging to the overthrust member. The faulting is clearly of later date than the overthrusting. The understanding of this relationship is of the utmost importance to the mining people of South Fork, who have never suspected the presence of a limestone series below the quartzites of the Reade and Benson ridge. The cherty limestones forming the ridge south of the Cardiff office and boarding house are the lifted, westward extension of that lower series upon which the overthrust block rests. The relation is clearly brought out in Section A-A, Plate VI (see also Plate III).

The direction of this movement is more nearly vertical than horizontal though the oblique flutings on the walls in the Cardiff tunnel indicate an important horizontal component toward the north on the west side. Surface evidence of faulting cannot be traced farther than the Cardiff

evidence of faulting could be found; but on the north wall of Big Cottonwood Canyon opposite South Fork, faulting is clearly shown. Here the west block has gone down instead of up. If this fault has anything to do with the Superior fault, it must be in the nature of a pivotal fault with the fulcrum somewhere between the Cardiff mine and the mouth of South Fork.

Silver Fork fault.—At the head of Silver Fork of Big Cottonwood Canyon, on the ridge north of Alta, there is a wall of limestone breccia which stands up from 10 to 20 feet above the crest of the ridge, having a direction nearly north and south. On both sides of it are limestones, but their metamorphic condition prevents close observation as to the stratigraphic displacement because of the difficulty of identifying a suitable datum plane on both sides. Farther to the south in the gulch leading from Alta to the City Rocks and Alta Consolidated mines, the quartzite and shale of Cambrian age are faulted up on the east so that they are in contact with the limestones which normally overlie them. The displacement is estimated to be between 500 and 600 feet, though the exact amount of movement could not be readily determined. It is, however, a fault of considerable magnitude. The fault surface seems to be vertical, and it is therefore impossible to say whether it is of the normal or the reversed type. Minor parallel faults may easily be detected to the west along the top of Emma Hill and Flagstaff Mountain, but on account of the strongly metamorphosed condition of the limestones, the throws have not been determined. They are, however, thought to be only slight. It might be said by way of generalization that the block between the Superior and Silver Fork faults has gone down and that the west end appears to have been most depressed. The parallel fractures between them, therefore, may show that the west side has gone down in most cases. This, however, is merely a suggestion and may not be true in all cases.

Minor faults.—In the various mines of Alta, minor faults are known to be of frequent occurrence. They conform generally to the main directions of fracturing already referred to as northeast-southwest and southeast-southwest. The latter are invariably found to be younger than the northeast-southwest series of faults. The Columbus Extension tunnel has been driven northwest for a considerable distance along one of these breaks. Near the mouth of the tunnel, a displacement of 90 feet has been observed, but farther to the north it is probably less. On the divide between South Fork and Alta, a fault with a throw of about 20 feet is

South of the Columbus Extension, in the Alta Hecla property, several of these north-south vertical faults are to be seen underground. Prospecting along them has failed to develop ore except where the northeast-southwest fissures have been crossed. In every case, these ore-bearing fissures are offset, showing them to be older. The amount of shifting has only been worked out in the one case above cited, as far as known, but generally the displacements are not very great, except in the two large faults already described.

SUMMARY OF CONCLUSIONS

PHYSIOGRAPHY

(a) The central Wasatch is a maturely dissected block mountain, preserving in a modified condition the form of its original profile.

(b) Before the Wasatch fault was formed, the folded Wasatch formations were planed off by erosion, and several plutonic igneous masses were uncovered, notably the Little Cottonwood granite, the Alta granodiorite and the Clayton Peak quartz diorite stocks.

(c) Block-faulting in Tertiary time gave rise to the Great Basin ranges, and at the same time the Wasatch block was uplifted. When newly formed, it had a steep western face and a long gentle eastern back slope.

(d) The original crest line was the upper edge of the great fault escarpment on the west. This was also the original divide.

(e) The divide has migrated from its first position near the western margin to its present position near the eastern margin of the block. The present long west-flowing streams of such canyons as Big and Little Cottonwood are chiefly obsequent streams, being consequent near their mouths.

(f) The crest line has moved in the same direction as the divide, but only a short distance.

(g) The Provo and Weber Rivers are probably also obsequent streams in their canyons across the Wasatch. Their head-waters are the eastern consequents that have been captured, so far as the drainage of the Wasatch is concerned.

(h) The mature dissection of the Wasatch by stream action was accomplished before the Pleistocene. Upon the stream-cut topography certain features were superposed due to glaciation during the Pleistocene. Later modifications have been slight.

STRATIGRAPHY

(i) The major part of the great quartzite and slate series exposed in Big Cottonwood Canyon is Algonkian and possibly Lower Huronian in age.

(j) The Lower Cambrian is separated from the Algonkian by a heavy basal conglomerate of widespread occurrence. The Cambrian strata of the central Wasatch belong to the lower and middle divisions of the Cambrian system and are less than one thousand feet thick.

(k) Above the known Cambrian are about 500 feet of unfossiliferous limestones and calcareous shales provisionally referred to the Ordovician. Silurian strata are entirely wanting in the Cottonwood region.

(l) Middle and Upper Devonian horizons are represented by what appears to be an unbroken succession of limestones carrying faunas closely allied to those found in western Colorado and Iowa.

(m) The Devonian beds rest with disconformity upon the lower limestones and are separated from them by a thin bed of conglomerate composed of limestone pebbles.

(n) The Mississippian follows the Devonian conformably and is represented by limestones of Lower and Middle Mississippian age which are separated by a continental formation.

(o) In the Cottonwood region, there is an unconformity between the Mississippian and the Pennsylvanian (Weber quartzite) which follows, representing a considerable erosion interval. The thinning of the Weber quartzite is probably to be accounted for by overlap upon this erosion surface.

(p) The Wasatch limestone of the Fortieth Parallel geologists embraces strata of Ordovician, Devonian and Mississippian ages. The Ogden quartzite and Ute limestone of supposed Devonian and Silurian ages respectively have no existence, as originally defined, in the central Wasatch.

STRUCTURE

(q) In the vicinity of Alta there is a great overthrust, presumably from east to west; the overthrust block consists of beds ranging in age from Algonkian through the Paleozoic and Mesozoic; the underthrust member consists of Devonian and older beds.

(r) The age of the overthrust is probably the same as the main foldings of the Wasatch, generally assigned to the end of the Cretaceous.

(s) After the overthrusting occurred, there followed a period of intrusion in which large irregular granitic and dioritic masses together with numerous dikes were injected into the Mesozoic and older formations.

(t) North-south faulting near Alta has resulted in the formation of two master faults and numerous minor fractures. These run roughly parallel to the main Wasatch fault line and probably belong to the same period of readjustment.

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PLATE I

**A. LOWER HALF OF SOUTH FORK OPPOSITE MILL D. BIG COTTONWOOD CANYON,
LOOKING NORTH**

**Shows broad U-shaped glacial trough, with terminal moraine at the junction
of the main canyon**

**B. CONGLOMERATE AT THE BASE OF THE CAMBRIAN QUARTZITE IN LITTLE COTTON-
WOOD CANYON, JUST BELOW ALTA**

PLATE I

FIG. 1. A. Lateral view of the head of the larva of the fly *Calliphora vicina* (Diptera: Calliphoridae) showing the position of the eye and the mouthparts.

FIG. 2. A. Lateral view of the head of the larva of the fly *Calliphora vicina* (Diptera: Calliphoridae) showing the position of the eye and the mouthparts.

FIG. 3. A. Lateral view of the head of the larva of the fly *Calliphora vicina* (Diptera: Calliphoridae) showing the position of the eye and the mouthparts.



A



PLATE II

A. PHOTOMICROGRAPH OF "TILLITE" FROM THE HEAD OF SOUTH FORK

Showing rounded and angular fragments, chiefly quartz, in a dark matrix,
principally biotite. Enlarged 25 diameters

B. PHOTOGRAPH OF HAND SPECIMEN OF "TILLITE" FROM SOUTH FORK

Showing rounded quartzite pebble in black groundmass. Natural size

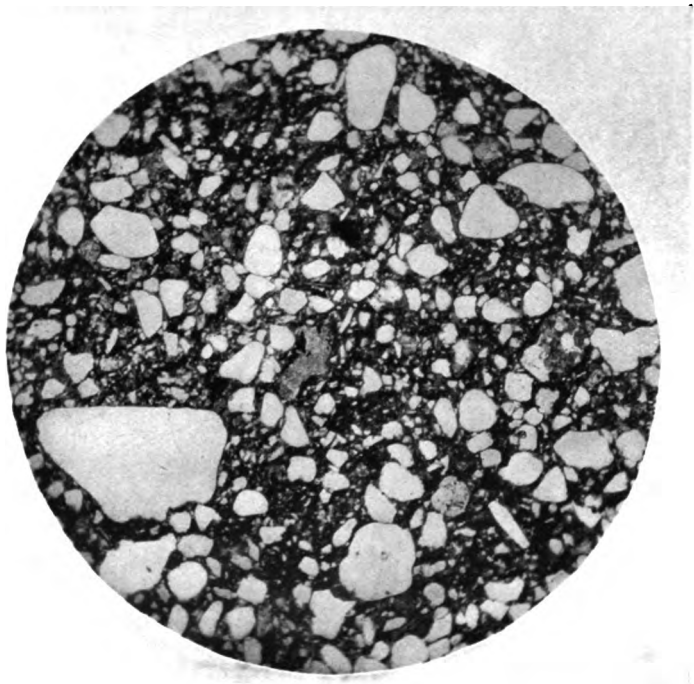
REPORT

OF THE PROCEEDINGS OF THE JOINT SELECT COMMITTEE ON HUMAN RIGHTS

IN RESPONSE TO RESOLUTION 18 OF THE HOUSE OF REPRESENTATIVES
PASSED MAY 2, 1994, AND SENATE RESOLUTION 1, 1994

AS SUBMITTED TO THE HOUSE OF REPRESENTATIVES AND SENATE

IN ACCORDANCE WITH RESOLUTION 18 OF THE HOUSE OF REPRESENTATIVES



A



PLATE III

**A. THE DIVIDE AT THE HEAD OF SOUTH FORK AND THE GEOLOGIC EXPOSURES OF
THE SOUTH END OF THE READE AND BENSON RIDGE**

Showing the overthrust members above the Superior fault

B. NEAR VIEW OF THE UPPER CENTRAL PART OF FIG. A

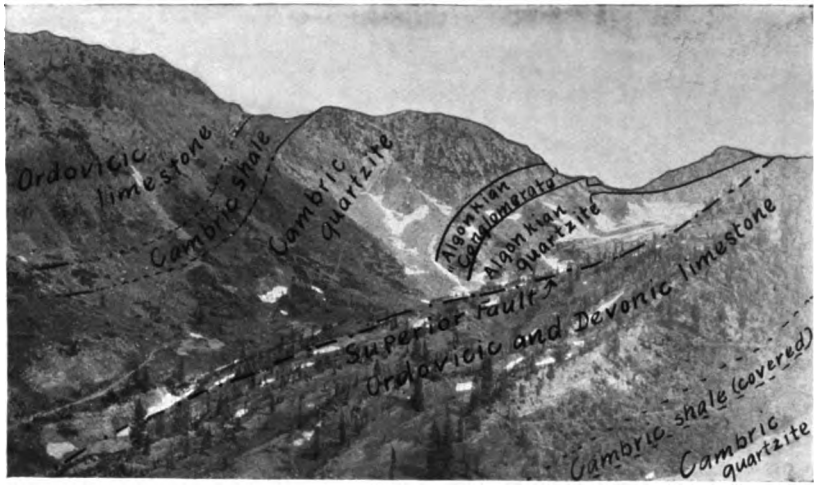
**Showing, from left to right, the Cambrian shale, Cambrian quartzite, Algonkian
"conglomerate" and quartzite**

10721

10722

10723

10724



A



PLATE IV

**A. ALTA OVERTHRUST AND GEOLOGIC EXPOSURES ON THE NORTH SLOPE OF LITTLE
COTTONWOOD CANYON**

Showing the duplication of beds. Looking north

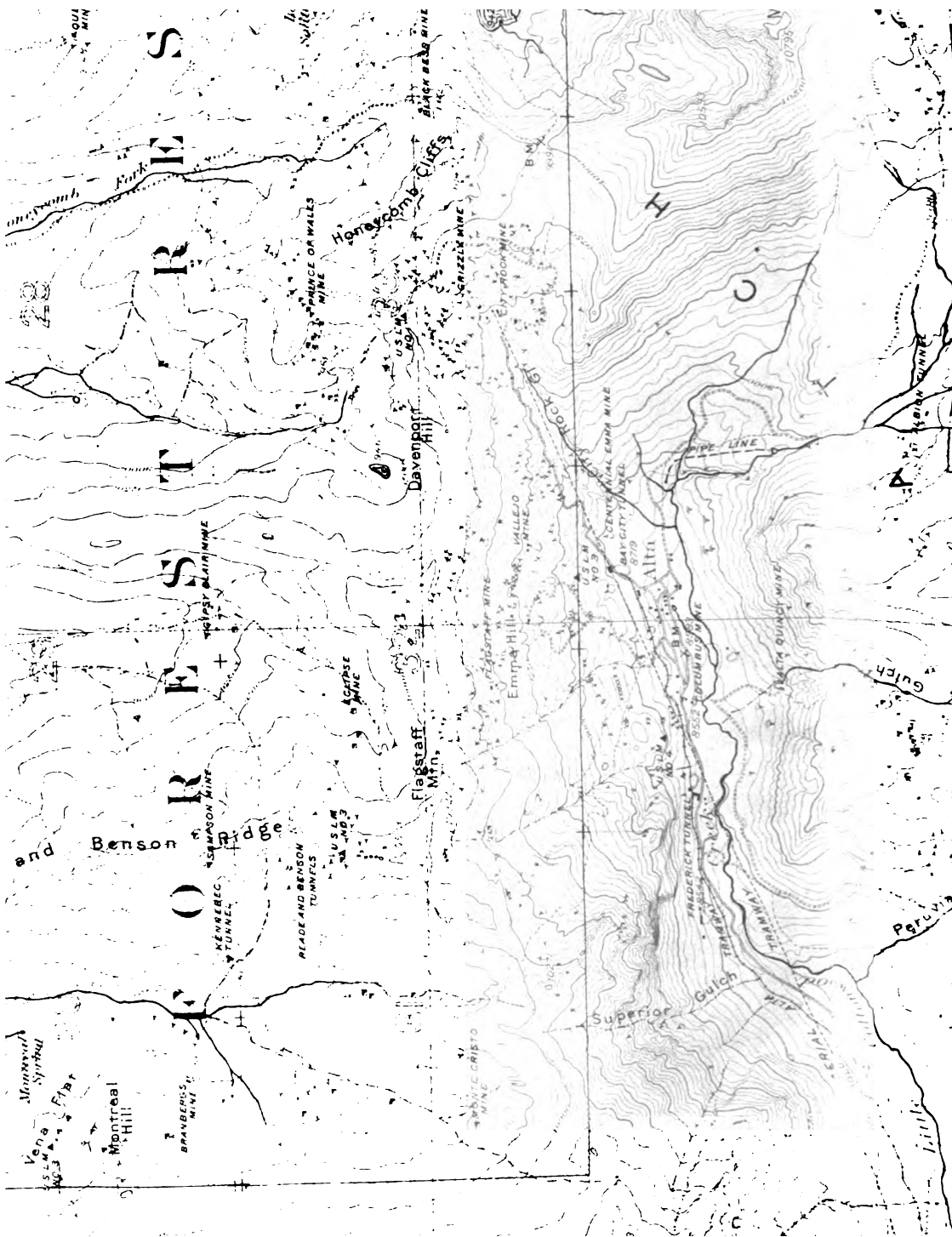
**B. NEAR VIEW OF THE EAST-SLOPING ALGONKIAN QUARTZITE SHOWN ON THE RIDGE
OF FIG. A**

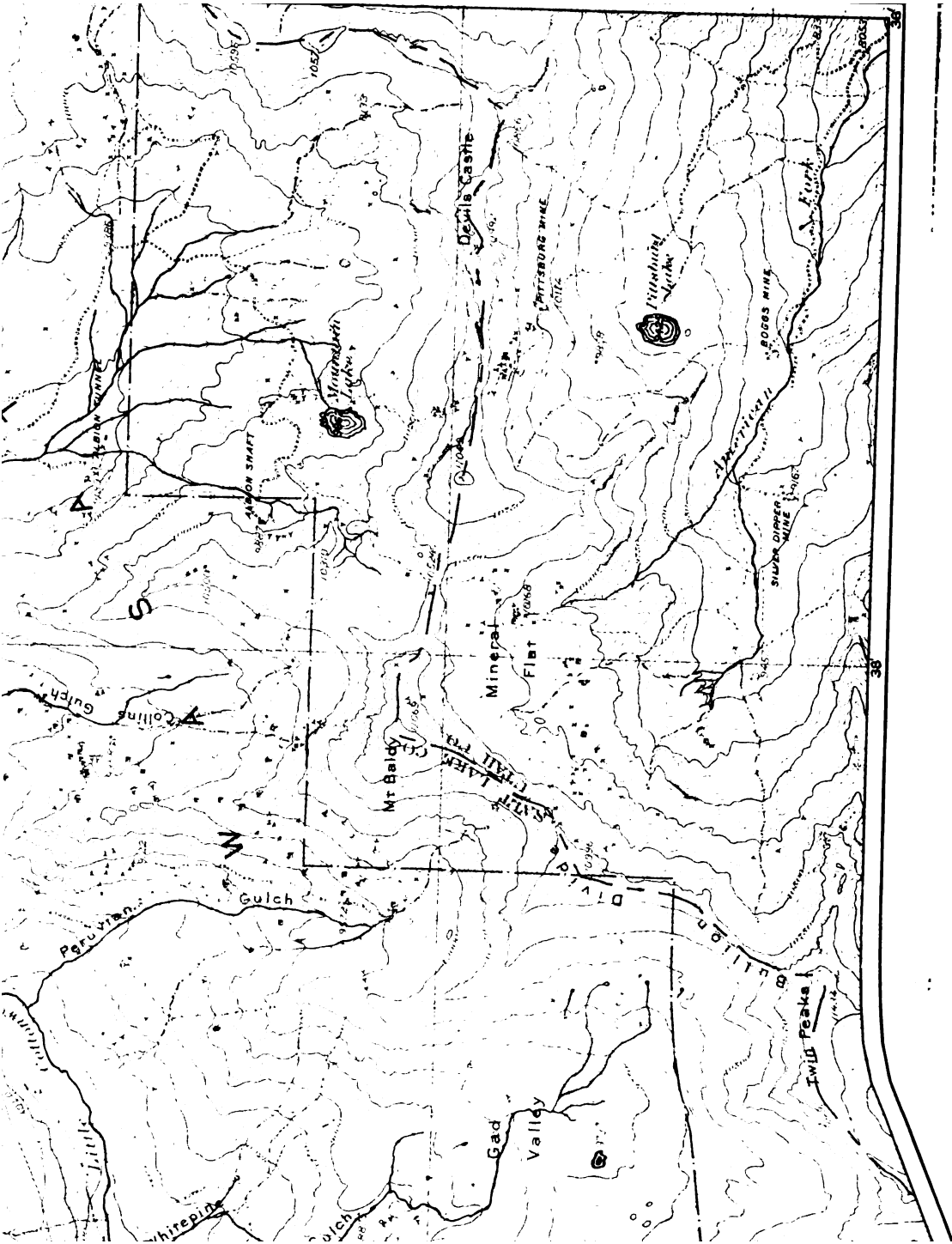
Showing the crumpled layers of hard quartzite

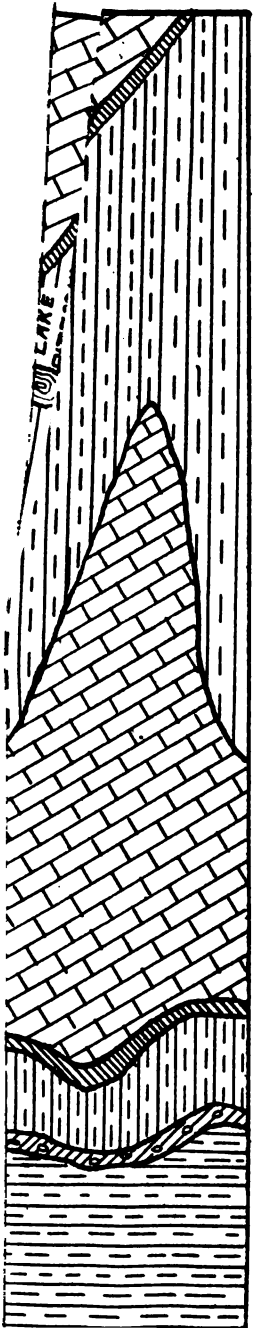


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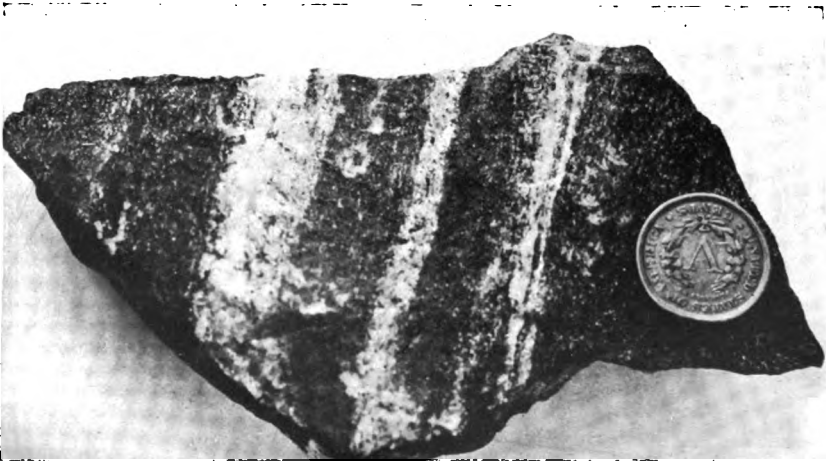


PLATE IX

PEGMATITE DIKES

- FIG. 1.** Pegmatite dike in Inwood limestone.
West 204th Street, east of Sherman Avenue, New York City.
- FIG. 2.** Banded pegmatite dike in Manhattan schist.
Speedway at Ft. George, New York City.

PLATE IX

PLATE IX

FIG. 1. The same like in *Lower Hesperia*.
FIG. 2. The same like in *Lower Hesperia*.

FIG. 3. The same like in *Lower Hesperia*.
FIG. 4. The same like in *Lower Hesperia*.



1



2

PLATE X

MANHATTAN SCHIST AND AUGEN GNEISS

**FIG. 1. Manhattan schist injected with pegmatite.
Near Rye, Westchester County, New York.**

**FIG. 2. "Augen" gneiss.
South of Bedford Village, Westchester, New York.**

PLATE X

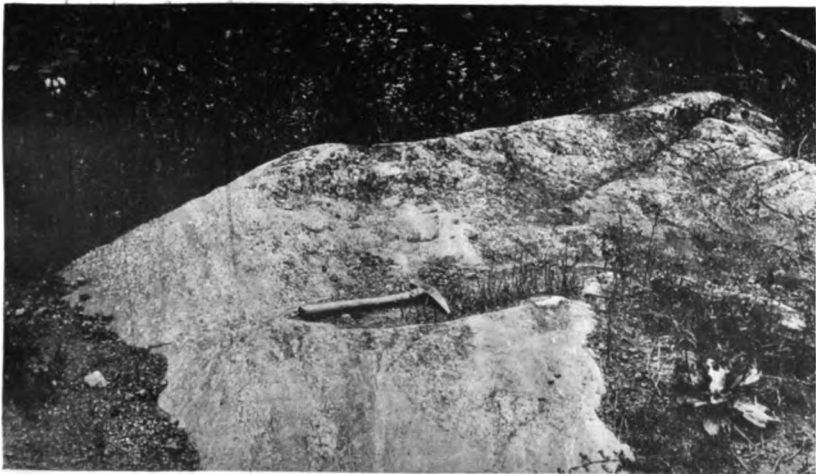
MAZDAHATTAH SCULPTURE AND ALCOVE

Fig. 1. Mazdahatta sculpture, showing the figure of the deity.

Fig. 2. Mazdahatta sculpture, showing the figure of the deity.



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PLATE XI

SPECIMENS OF AUGEN GNEISS

- FIG. 1. "Augen" gneiss.**
South of Bedford Village, Westchester County, New York.
- FIG. 2. "Augen" gneiss.**
South of Bedford Village, Westchester County, New York.

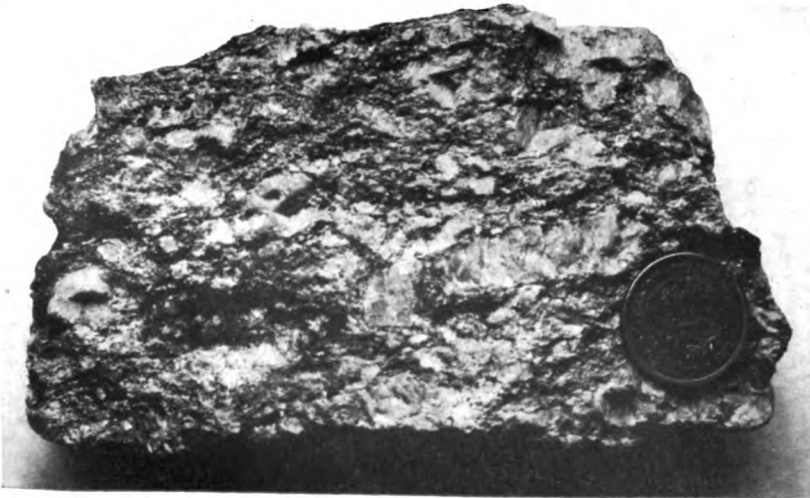
PLATE XI

SPERMATOPHYTES

Fig. 1. *Juniperus communis* L.
South of Berlin, Prussia, 1890. (From the Berlin Herbarium.)
Fig. 2. *Juniperus communis* L.
South of Berlin, Prussia, 1890. (From the Berlin Herbarium.)



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2

PLATE XII

PHOTOMICROGRAPHS OF GNEISS, SCHIST AND GRANODIORITE

- FIG. 1. Interbedded gneiss.**
Catskill Aqueduct tunnel underneath Harlem River at High Bridge,
New York City.
Magnified 22.5 diameters. Crossed nicols.
- FIG. 2. Fordham gneiss.**
East of High Bridge, New York City.
Magnified 22.5 diameters. Crossed nicols.
- FIG. 3. Cyanite schist.**
West 120th Street, east of Amsterdam Avenue, New York City.
Magnified 22.5 diameters. Crossed nicols.
- FIG. 4. Hornblende schist.**
South shore, Croton Lake, New York.
Magnified 22.5 diameters.
- FIG. 5. Harrison granodiorite.**
Greenwich, Connecticut.
Magnified 22.5 diameters.

1917

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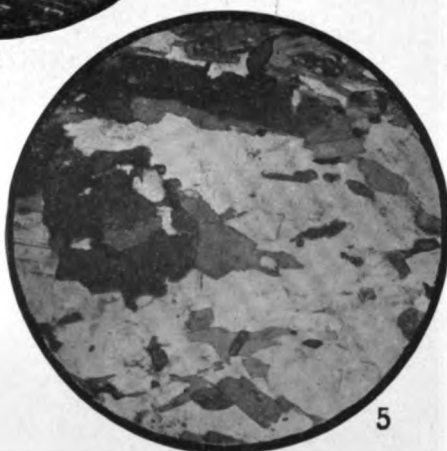
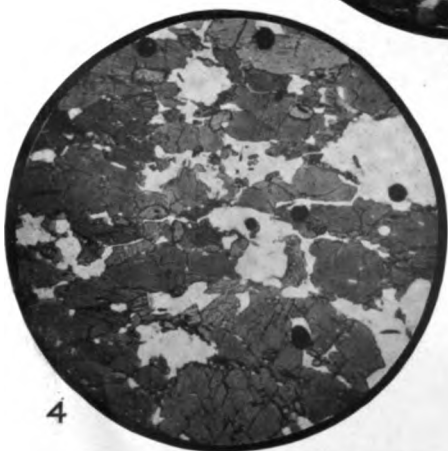
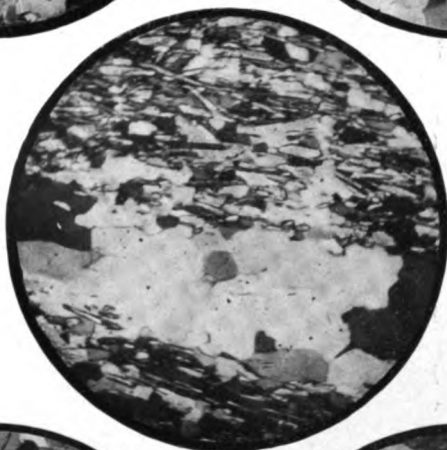
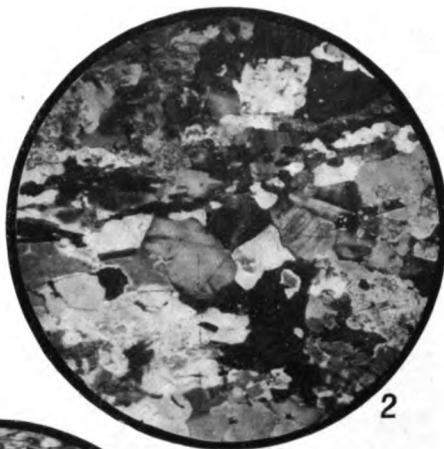
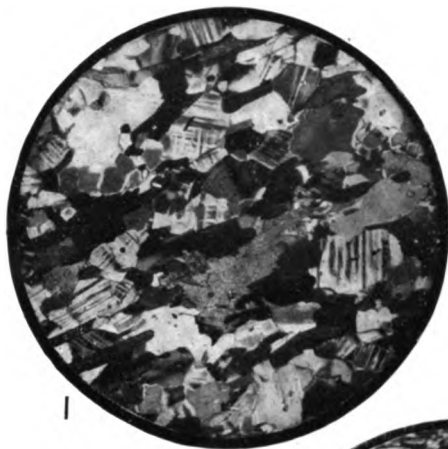


PLATE XIII

PHOTOMICROGRAPHS OF SCHIST

- FIG. 1.** Mica-feldspar-quartz schist.
Southeast corner West 116th Street and Broadway, New York City.
Magnified 22.5 diameters.
- FIG. 2.** Gray gneissoid variety of schist.
West 42nd Street, near 5th Avenue, New York City.
Magnified 22.5 diameters. Crossed nicols.
- FIG. 3.** Mica schist.
Verplanck, Westchester County, New York.
Magnified 22.5 diameters. Crossed nicols.
- FIG. 4.** Mica schist.
North of Croton-on-the-Hudson, Westchester County, New York.
Magnified 22.5 diameters.
- FIG. 5.** Staurolite mica schist.
North of Croton-on-the-Hudson, Westchester County, New York.
Magnified 22.5 diameters.

PLATE XIII

PHOTOMICROGRAPHS OF SOLID

Fig. 1. *Micrograph of solid.*
 Southern corner West Hudson, New York, 1907.
 Diameter 22.5 diameters.

Fig. 2. *Micrograph of solid.*
 Southern corner West Hudson, New York, 1907.
 Diameter 22.5 diameters.

Fig. 3. *Micrograph of solid.*
 Southern corner West Hudson, New York, 1907.
 Diameter 22.5 diameters.

Fig. 4. *Micrograph of solid.*
 North of Hudson, West Hudson, New York, 1907.
 Diameter 22.5 diameters.

Fig. 5. *Micrograph of solid.*
 North of Hudson, West Hudson, New York, 1907.
 Diameter 22.5 diameters.

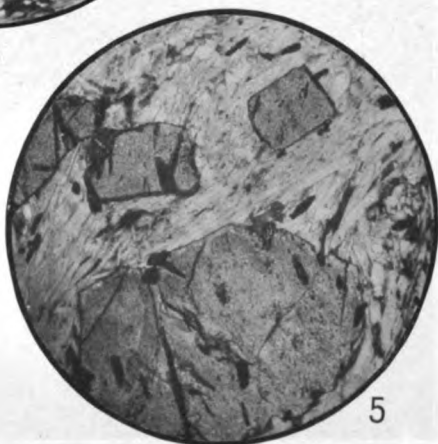
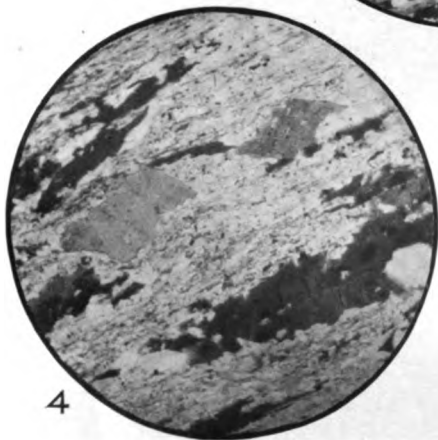
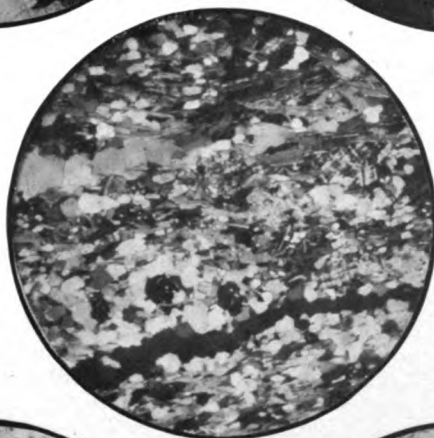
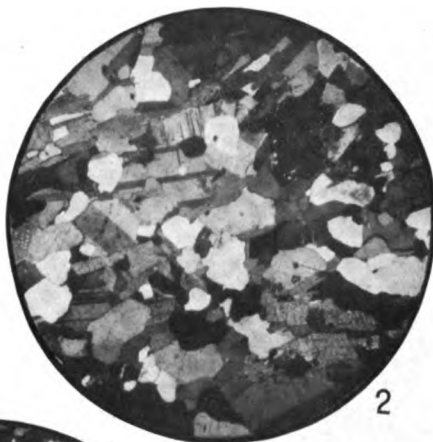
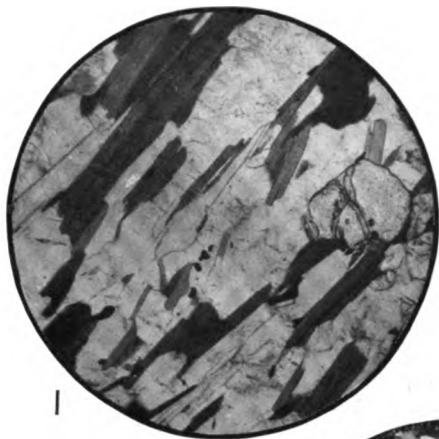


PLATE XIV

PHOTOMICROGRAPHS OF PHYLLITE AND SCHIST

- FIG. 1. Phyllite.**
East of Peekskill Creek Valley, New York.
Magnified 22.5 diameters. Crossed nicols.
- FIG. 2. Phyllite.**
East of Clove Valley, Dutchess County, New York.
Magnified 22.5 diameters. Crossed nicols.
- FIG. 3. Mica schist.**
West of Wingdale, Dutchess County, New York.
Magnified 22.5 diameters.
- FIG. 4. Stauroilite mica schist.**
West of Wingdale, Dutchess County, New York.
Magnified 22.5 diameters. Crossed nicols.
- FIG. 5. Mica-feldspar-quartz schist.**
East of Pawling, Dutchess County, New York.
Magnified 22.5 diameters. Crossed nicols.

PLATE XIV

THE GARDEN OF THE GARDEN AND THE GARDEN

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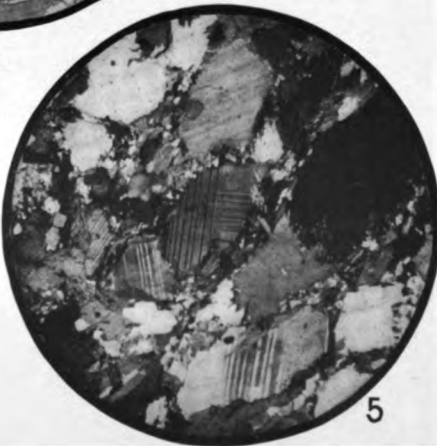
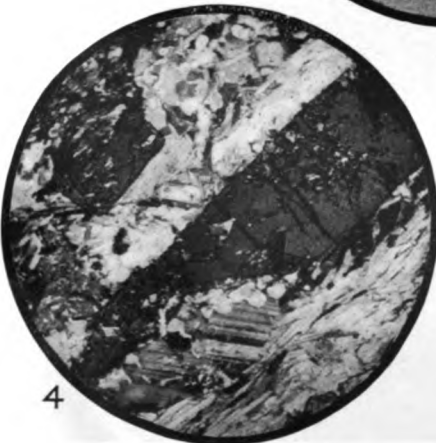
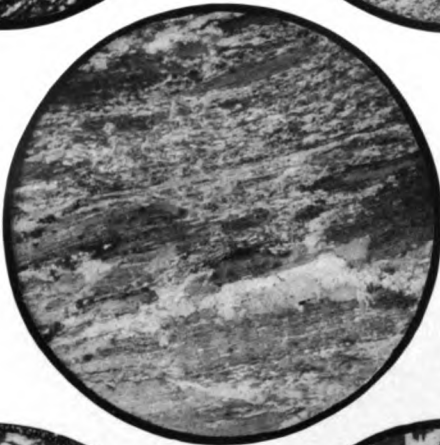
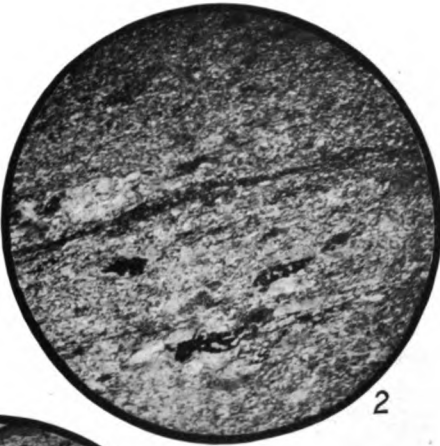
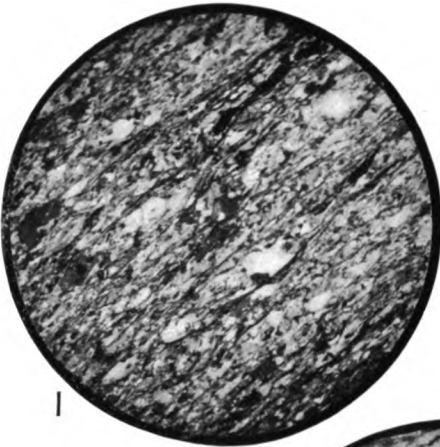


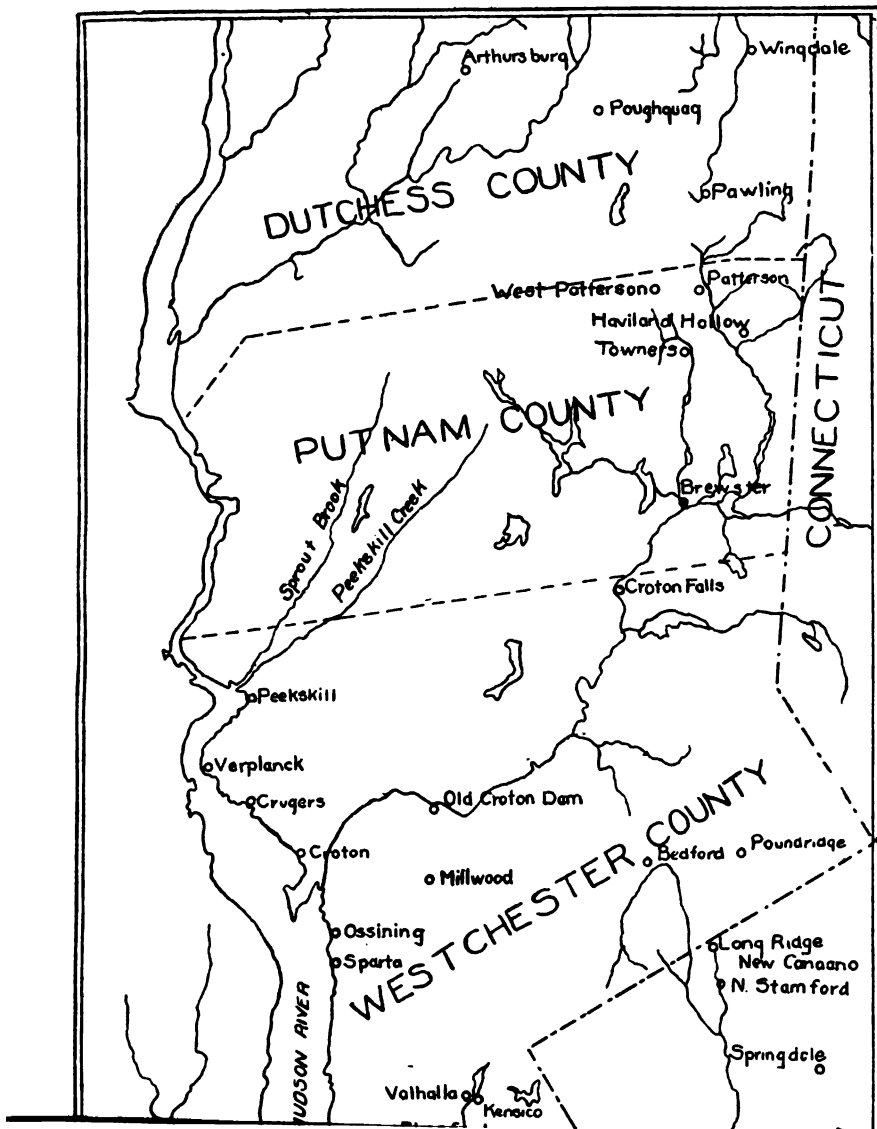
PLATE XV

OUTLINE MAP OF SOUTHEASTERN NEW YORK

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